[redacted]

CONTRACT REQUIREMENTS	CONTRACT ITEM	MODEL	CONTRACT NO.	DATE
Exhibit E	Para. 5.1	LEM	NAS-9-1100	4/1/63

Type II

Primary Code 008

[redacted]

REPORT

NO. LED-390-2

DATE: 1 April 1963

ELECTRICAL POWER SYSTEM CONFIGURATION STUDY [redacted]

CODE 26512

[redacted]

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REVISIONS

DATE	REV. BY	REVISIONS & ADDED PAGES	REMARKS

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ABSTRACT

This report contains the results of the various analyses performed during the LEM Electrical Power Subsystem (EPS) configuration study. The specific tasks performed in the study are:

1. Updating of the mission profile

2. Determination of the power profile for the revised mission profile.

3. Determination of the optimum configuration of the EPS; considering
   (a) fuel cells, hydrogen expansion engine, and silver-zinc batteries as the primary power sources,
   (b) staged and unstaged configurations,
   (c) integration with the thermal control loop of the Environmental Control Subsystem.

The primary evaluation factors used in comparing configurations and power sources are:
   (a) total effective subsystem weight at LEM-CSM separation
   (b) relative reliability.

The configuration that has been selected as optimum for the LEM consists of:
   (a) three (3) fuel cell units in the ascent stage,
   (b) the cryogenic tank arrangement utilized for comparing the power sources consisted of one hydrogen tank sized for the complete mission with one redundant hydrogen tank sized for the ascent phase and one oxygen tank sized for the complete mission with one redundant tank sized for the ascent phase.

The final cryogenic tank arrangement will be determined by performing the integrated oxygen tank study in conjunction with the ECS.

Further study is required to determine if the fuel cell peaking batteries can be sized to operate as an emergency ascent battery within a reasonable weight penalty.

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SECTION I - INTRODUCTION

This report contains the results of the various analyses performed during the LEM Electrical Power Subsystem technical configuration study.

Subsequent to the start of the Technical Study, it was found that procurement regulations and format arrangements for acquisition of data from other Apollo Contractors would tend to impede progress on such items as costs, schedules, and resolution of interface problems. It was also found that the necessary information to resolve the question of centralized vs. individual inverters would take more time to process than the established study period. We are working on these items, but for the purposes of the study have concentrated on the Electrical PowerSupply Configuration. The specific tasks covered to date are as follows:

1. Re-examine LEM Mission Profile and determine power profile for the LEM mission.

2. Establish a rational approach to assignment of reserve quantities and component redundancy.

3. Determine the optimum arrangement of fuel cells staged with batteries, and of unstaged power systems with and without integration into the Environmental Control System, from the standpoint of:

   (a) Total effective weight.

   (b) Reliability.

SECTION II - CONCLUSIONS

1. The unstaged fuel cell configuration that has been selected as optimum for the LEM EPS power generation section consists of three (3) fifty percent units.

2. The cryogenic tank arrangement utilized for comparing the selected EPS configuration consisted of:

   (a) One hydrogen tank sized for the complete mission with one redundant hydrogen tank sized for the ascent phase.

   (b) One oxygen tank sized for the complete mission with one redundant tank sized for the ascent phase.

3. The final cryogenic tank arrangement will be determined by performing the integrated oxygen tank study in conjunction with the ECS.

4. Further study is required to determine if the fuel cell peaking batteries can be sized to operate as an emergency ascent battery within a reasonable weight penalty.

5. Listed below is a summary of a qualitative analysis performed on the relative merits of using fuel cells or the Cryhocycle for the LEM EPS.

Evaluation Factor	Relative Rating	
	Fuel Cells	Cryhocycle
Reliability	1	1
Effective Weight	1	1
Volume	1	2
Installation & Maintainability	1	2
Demonstrated Study Performance	1	2
Effect on ECS Configuration	1	2
Design Simplicity	1	2
Common Usage	1	2
Thermal Compatibility	1	1
Development Status	1	2
Power Growth	1	1
Energy Growth	1	2
Effect on C.G. and LEM Configuration	1	2
Compatibility with CSM Controls	1	2

It was concluded that although the Cryhocycle is competitive on a weight and reliability basis, other important considerations as indicated in the table above are sufficient to decide the issue in favor of fuel cells.

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Compatibility with CSM Controls	1	2

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SECTION III - ELECTRICAL LOAD ANALYSIS

Because the LEM mission profile is still in process of refinement, three profiles, covering various contingencies were detailed and a load analysis performed for each. The guide lines used in determining mission profiles were:

Work Statement (Exhibit "B" dated 20 December 1962)

Paragraph 2.1.2.4.1 (2 day LEM)
* Paragraph 4.3.1.1.2 (heater power for I.M.U.)

NOTE: * This requirement established the need to operate the LEM power system during translunar flight.

The differences between the three profiles occur in the amount of time alloted for rendezvous contingency.

Mission "A" -- 6 Hours (4.5 hours cont.)

Mission "B" -- 12 Hours (10.5 hours cont.)

Mission "C" -- 18 Hours (16.5 hours cont.)

The following is the mission profile used to perform the electrical load analysis for mission "C".

PHASE	OPERATION	TIME(hrs.)	Kw(hrs.)
1	Translunar	65.3	12.1
2	Pre-separation checkout	2.5	2.47
3	Lunar Orbit	2.1	3.13
4	Descent	0.5	0.86
5	Terminal Descent	0.1	0.17
6	Post Landing Checkout	2.3	2.26
7	Lunar Stay	21.9	17.3
8	Pre-launch Checkout	3.1	3.27
9	Ascent and Rendezvous	1.5	2.56
10	Rendezvous Contingency	16.5	17.0
11	Crew Transfer	0.5	0.2

The same profile was used for missions A and B with the exception that for mission "A" phases 9 and 10 covered 6 hours, and for mission "B" phases 9 and 10 covered 12 hours. The time added to the contingency allowance was subtracted from the lunar stay time such that the nominal mission is retained at 48 hours. To this nominal mission provisions for pre-separation and final crew transfer were added.

SECTION III - ELECTRICAL LOAD ANALYSIS - Continued

The results of the three load analysis as of 28 January 1963 are as follows:

	Total Energy Required Kw Hours	Max Power (Steady State)	Min Power (Steady State)
Mission A	57*	1725	525
Mission B	59.2*	1725	525
Mission C	61.3*	1725	525

NOTE: * With power available from the CSM these figures are reduced by 12.1 Kw hour.

Profiles for each of the three missions can be found in section IV of this report. Load Analysis information is also available from the following documents:

Drawing 390-10000 (dated 28 January 1963) "Electrical Load Analysis and Mission Profiles"

LEM Memorandum L390-M03-2 dated 30 January 1963 entitled, "LEM Electrical Load Analysis"

SECTION IV - BATTERIES

Battery Introduction

Silver-Zinc batteries were selected for battery applications for use in the Technical Study. The higher energy densities obtainable and their proven use on various space programs, formed the basis for considering only this type of battery.

Primary and secondary operation was considered. Secondary battery operation was chosen to enable full exercise of the battery before actual use. In particular, the secondary batteries referred to herein, are capable of five full charge-discharge cycles or a greater number of partial cycles.

To obtain data three companies, representative of those in industry, were invited to a Technical conference held January 28, 1963. Each of the three companies, Eagle-Picher, Electric Storage Battery, and Yardney were presented with a package of information (contained herein) which contained:

1. Battery specification
2. Load profiles for missions A, B, and C
3. Delivery schedule
4. Returnable data forms

The companies were asked to respond by February 13, 1963.

The supporting data for the battery configuration study is contained in the appendix.

Establishment of Merit Factor

The initial data received was not consistent among the three companies. Wide variances in weight, volume and reliability for a particular size battery existed. Although provided with the same mission profiles, the companies took different design approaches to fulfill the battery requirements. Eagle-Picher responded with data based on a one-shot primary battery, while E.S.B. and Yardney supplied data for a secondary battery. Graphs G-1 through G-4 represent the data originally received.

To arrive at weight, volume and reliability figures for the selected battery configuration (The ascent portion of configuration B-5 is the selected configuration. Batteries for the total mission, either staged or unstaged were eliminated on a weight basis when compared to other methods of supplying power for the LEM vehicle.) and to enable the companies to respond with the same basic design criteria, the battery capable of five full charge-discharge cycles. Graphs G-5 through G-8 represent the revised data. Graph G-9 is a summary of the original data received for energy density figures.

Since variances still existed, it was necessary to make a judgement as to what weight, volume and reliability factors should be applied to the selected configuration.

To determine the energy density factor to apply, the following criteria was used:

1. The revised data received from the companies.

2. The indications of all graphs which show that within limits, as the capacity of the battery increases the obtainable energy density increases.

3. The results achieved on the Mercury Spacecraft program which indicate that for a 3 Kw hr. battery a merit factor of 68 watt-hour/lb. has been obtained and for 1.5 Kw hr. battery a merit factor of 60 watt-hour/lb. has been obtained. The construction of these batteries is such that the individual cells are sealed, while the battery container has venting provisions.

4. A tested battery built for Project Surveyor which resulted in a merit factor of 89 watt-hour/lb. for a 4.1 Kw hr., 21 volt battery.

In light of the above, the following merit factors were chosen:

1. For mission "A" ascent - 60 watt-hour/lb. batteries.

2. For mission "B" ascent - 70 watt-hour/lb. batteries.

3. For mission "C" ascent - 80 watt-hour/lb. batteries.

4. Descent batteries for - 85 watt-hour/lb. all missions.

Graph G-11 shows Grumman's estimate for obtainable energy density and form S-10 shows the application of these data to the selected configuration. Volume factors used are shown on form S-10.

Discussion of Battery Evaluation

1. General

The power demands for the LEM spacecraft are such that an Electrical Power System having very high reliability, capability of delivering peak energy for short periods of time, and ability to operate under adverse environmental conditions is required. It is for these reasons that batteries were evaluated for both total and partial mission requirements.

The battery evaluation was limited to the silver oxide/zinc battery, of sealed construction because its specific energy is very high compared to other battery types used in spacecraft requiring large power demands. In addition to high reliability, ability to operate under adverse environmental conditions, and capability of delivering energy for high peak demands for short periods of time, the silver oxide/zinc batteries considered for LEM have the following advantages:

(a) Ability to operate at varying discharge rates
(b) Long activated stand life
(c) Flat discharge voltage curve except for the initial or divalent portion
(d) Ability to be recharged up to about 5 cycles
(e) Ruggedness
(f) Minimum maintenance requirements

The sealed silver oxide/zinc battery was considered during the study for the following applications:

(a) Batteries for total mission, in both staged and unstaged configurations
(b) Batteries for ascent, rendezvous, and crew transfer stages only
(c) Batteries for peak loads only - operating in conjunction with fuel cells as the primary power source
(d) Batteries for emergency operation

To obtain data for this study, a technical conference was convened on January 28, 1963 attended by:

(a) Eagle-Picher Company
(b) Electric Storage Battery Company
(c) Yardney Electric Corporation

These companies are representative of those engaged in the design, development, and manufacture of silver oxide/zinc batteries for space applications.

At the time of the meeting, each company was presented with a technical package containing the following:

(a) Battery Requirement Specification
(b) Load Profiles for Missions A, B, and C
(c) Environmental Criteria
(d) Delivery Milestone Data
(e) Format for submittal of Battery Information and Data

The format of the "request for Technical information and data" was such to facilitate comparisons of various configurations. The various configurations are tabulated in the attached summary sheets numbered US-1 through S-11, and the discussion that follows is keyed to these summary sheets.

2. Evaluation of Unstaged Battery Configurations - Forms US-1 through US-3

Unstaged batteries for the total LEM mission were evaluated for six different battery configurations. The purpose of postulating different configurations was to arrive at the best combination considering weight, volume, and reliability. The six battery configurations evaluated are as follows:

(a) Configuration A-1 consists of a single battery having 100% capacity for the total mission requirements.
(b) Configuration A-2 consists of two batteries, each having 50% capacity of the total mission requirement, and are connected for parallel operation, or one may be on standby.
(c) Configuration A-3 consists of two batteries, one having 100% capacity and the second 50% capacity of the total mission requirement. The 50% capacity battery is on standby, and is connected upon loss of the main battery.
(d) Configuration A-4 consists of two batteries, each having 100% capacity for the total mission requirement. One battery is on standby.
(e) Configuration A-5 consists of three batteries, each having 50% capacity of the total mission requirement. The batteries may be connected two in parallel with one on standby.
(f) Configuration A-6 consists of three batteries, one having 100% capacity, and each of the two remaining having 50% capacity of the total mission requirement. The two 50% capacity batteries are on standby and are connected in sequence upon loss of the main battery.

Evaluation summary form US-1 is a tabulation of the original data received from Eagle-Picher for the six unstaged configurations for the total LEM mission. Evaluation summary form US-2 tabulates the original data received from Electric Storage Battery, and Evaluation summary form US-3 tabulates the original data received from Yardney.

Configurations A-4 and A-5 emerge as successful unstaged battery configurations. However, when compared with other electrical power sources, an unstaged battery configuration for total mission requirements is not to be recommended because of excessive weight. The next logical step, therefore, was an evaluation of battery arrangements in staged configurations.

3. Evaluation of Staged Battery Configurations - Forms S-1 through S-11

For purposes of defining the staged battery configurations for descent and ascent, the battery required to furnish the power requirements for the translunar phase through the lunar prelaunch checkout phase (Phases 1 through 8 as referred to on the summary forms) is defined as the descent battery, and the battery required to furnish the power requirements during the ascent, rendezvous, and crew transfer (Phases 9 through 11) is defined as the ascent battery.

A total of 12 different staged configurations were evaluated in order to arrive at the optimum arrangement for staged battery configurations, again, the principal criteria considered are weight, volume and reliability.

The 12 battery arrangements considered for staged configurations are as follows:

(a) Configuration B-1 consists of one descent battery and one ascent battery each having 100% capacity for the mission phase requirement.
(b) Configuration B-2 consists of two 100% descent capacity batteries and two 100% capacity ascent batteries. Each redundant battery is on standby until loss of the main battery occurs.
(c) Configuration B-3 consists of two descent batteries, one having 100% capacity and the second 50% capacity; and two ascent batteries, one having 100% capacity and the second having 50% capacity.
(d) Configuration B-4 consists of two 50% capacity descent batteries and two 50% capacity ascent batteries. The batteries may be connected for parallel operation, or one may be on standby.
(e) Configuration B-5 consists of three 50% capacity descent batteries and three 50% capacity ascent batteries. Each stage may be connected with two batteries operating in parallel with one on standby.
(f) Configuration B-6 consists of one 100% capacity descent battery; and two ascent batteries, one having 100% capacity and the second having 50% capacity. The redundant ascent battery is on standby.
(g) Configuration B-7 consists of two 50% capacity descent batteries, with the ascent batteries consisting of two 50% ascent capacity batteries and one 50% descent capacity battery. The two main descent and ascent batteries may be connected for parallel operation or one may be on standby until loss of the first battery occurs. The redundant 50% descent capacity battery is arranged to supply power for either the descent or ascent phases in the event of total power loss during either phase.
(h) Configuration B-8 consists of two 50% capacity descent batteries; and two ascent batteries, one having 100% capacity and the second having 50% capacity. The redundant ascent battery is on standby.

(i) Configuration B-9 consists of one 50% capacity descent battery, and two ascent batteries, one having 100% capacity and the second having 50% capacity. The redundant ascent battery is on standby.

(j) Configuration B-10 consists of two descent batteries, one having 100% capacity and the other 50%, and two 100% capacity ascent batteries. Each redundant battery is on standby.

(k) Configuration B-11 consists of one 100% capacity descent battery, and two 100% capacity ascent batteries. The redundant ascent battery is on standby.

(l) Configuration B-12 consists of two 50% capacity descent batteries, and three 50% capacity ascent batteries. The batteries in each stage may be operated two at a time in parallel, or arranged to be connected in sequence.

Evaluation summary forms S-1 and S-2 are a tabulation of the original data received from Eagle-Picher for the twelve staged configurations for the total LEM mission. Evaluation summary forms S-3 and S-4 tabulates the original, data received from Electric Storage battery, and evaluation summary forms S-5 and S-6 tabulates the original data received from Yardney.

Configuration B-2, B-5, B-7 and B-12 emerged as probable successful staged battery configurations, and these configurations are separately tabulated for each battery company on Evaluation summary forms S-7. From these four configurations, B-5 emerges as the best staged battery configuration on the basis of reliability. This configuration is separately tabulated for each of the three missions considered for each battery company on evaluation summary form S-8. Evaluation summary form S-9 is a tabulation of the revised data for configuration B-5 for each of three battery companies for each of the three missions. Form S-10 represents Grumman's weight estimates for this configuration for each of three missions.

However, when compared with other electrical power sources, the best staged battery configuration cannot be recommended on the basis of weight.

4. Evaluation of Peaking Battery Configurations

A peaking battery is required to operate in conjunction with fuel cells in order to maintain load bus voltage regulation for peak loads. The fuel cells are intended to supply the average power required for the LEM mission for loads up to 1723 watts and maintain the specified voltage regulation limits of 26 - 30 volts. For the peak loads that occur at varying intervals and rates up to a maximum of 3223 watts, a peaking battery is required. The peaking battery will be a sealed silver oxide/zinc type similar to the type of battery considered in this report as a primary battery. The battery will be installed in the spacecraft in a wet, charged condition.

The data received from the three battery companies for various battery configurations is summarized on Evaluation Summary Form P1, and was based on the requirement that the peaking battery be sized for all loads greater than 1500 watts. Using this data, the primary criteria of weight and reliability for the mission were evaluated, and it was established that two 50% capacity batteries operating in parallel would meet the LEM requirements. In addition, a separate Grumman estimate was prepared for the peaking battery size and capacity required to supply loads in excess of 1723 watts. This estimate shows that the peaking battery would have a total configured weight of 20 pounds, and a total capacity of 900 watt-hours, or 40 ampere-hours. The

capacity of the battery includes sufficient reserve design so that it will be suitable for use as either a primary or secondary battery.

Consideration must be given to the means by which the battery is connected to the d-c load bus. If the battery is directly connected and the battery is in a high state of charge, it will tend to discharge to follow the voltage dips of the fuel cell. If the fuel cells are then used to recharge the peaking battery during periods when the voltage has recovered, a control system must be developed to regulate the charging rate of the battery to prevent overcharge, as well as to minimize the loading of the fuel cells and conserve the consumption of fuel. In addition, the circuitry must minimize any ripple that may be introduced into the system during connection and disconnect of the peaking battery. The optimum configuration will be determined during a subsequent evaluation.

Emergency Battery

Emergency considerations for the LEM Electrical Power Subsystem are covered in LEM Memo L390-M03-5 dated to February 1963. In this memo reference was made to provide separate emergency provisions over and above the normal power subsystem. The application of a battery for this situation is discussed here.

1. Assumptions

(a) Main power source fails
(b) Failure occurs on moon
(c) Provide enough power to return crew to CSM or have CSM rescue orbiting LEM

2. Requirements

The total time required for this operation has been figured at roughly 3.5 hours (i.e. 2 hour wait on moon plus 1.5 hours for ascent and rendezvous) the power required is estimated at an average of 425 watts. The energy required for this operation is therefore, 1.5 Kw hrs. Based on an energy density of 60 watt-hours per pound a battery to supply this requirement would weigh approximately 25 lbs.

If this emergency is provided for, its requirements could be combined with the peaking batteries previously described resulting in an overall weight savings to the vehicle. In this case the battery would be an active part of the overall system in that recharging capabilities would be provided to restore the energy used during peak transient load operation. In this manner the battery would be fully charged, should the emergency occur.

MODIFIED HANDLING AUTHORIZED

LEM BATTERY CONFIGURATIONS

COMPANY EAGLE-PICHER

UNSTAGED — MISSION — "C"

•• PHASE — I-II ••

US-1

		UNIT		CONF. A-1	CONF. A-2		CONF. A-3		CONF. A-4		CONF. A-5			CONF. A-6		
		100%	50%	100%	50%	50%	100%	50%	100%	100%	50%	50%	50%	100%	50%	50%
WEIGHT	CONF. (#)	600	335	600	670		935		1200		1005			1270		
	WEIGHTED (#)	3060	1708	3060	3416		4768		6120		5124			6476		
VOLUME (IN^3)		6700	4800	6700	8400		10900		13400		12600			15100		
RELIABILITY	R_C	.981900	.990000	.981900	.999900		.999819		.999672		.999999			.999999		
	Q_C^{X10-6}	18100	10000	18100	100		181		328		1.0			1.81		
	R_M^{X10-6}	.981900	.990000	.981900	.98		.981719		.999672		.999700			.999638		
	Q_M^{X10-6}	18100	10000	18100	20000		18281		328		300			362		
MERIT	WHR/#	103	92	103	92		99		103		92			97		
	AH/#	3.7	3.3	3.7	3.3		3.5		3.7		3.3			3.5		
	WHR/IN^3	9.2	7.0	9.2	7.0		8.5		9.2		7.0			8.2		
	#/IN^3	0.09	0.08	0.09	0.08		0.09		0.09		0.08			0.08		

Contract No. NAS9-1100
Primary Code 008

MODIFIED HANDLING AUTHORIZED
GRUMMAN AIRCRAFT ENGINEERING CORPORATION

REPORT LED-390-2
DATE 1 April 1963

[redacted] MODIFIED HANDLING AUTHORIZED

LEM BATTERY CONFIGURATIONS

COMPANY ELEC STORAGE BATTERY

UNSTAGED — MISSION — "C"

•• PHASE — I-II ••

US-2

		UNIT		CONF. A-1	CONF. A-2		CONF. A-3		CONF. A-4		CONF. A-5			CONF. A-6		
		100%	50%	100%	50%	50%	100%	50%	100%	100%	50%	50%	50%	100%	50%	50%
WEIGHT	CONF. (#)	897	426	897	852		1323		1794		1278			1749		
	WEIGHTED (#)	4580	2175	4580	4350		6755		9160		6525			8930		
VOLUME (IN^3)		127500	6440	12750	12880		19190		25500		19320			25630		
RELIABILITY	Rc			.998024	.999996		.999996		.999996		.99999999			.99999999		
	Qc^{X10-6}			1976	4		4		4		.01			.01		
	RM^{X10-6}			.998024	.996048		.998024		.999996		.9999883			.9999922		
	QM^{X10-6}			1976	3952		1976		4		11.7			8		
MERIT	WHR/#	89	86	89	86		87		89		86			87		
	AH/#	3.2	3.1	3.2	3.1		3.1		3.2		3.1			3.1		
	WHR/IN^3	6.2	5.7	6.2	5.7		6.0		6.2		5.7			5.9		
	#/IN^3	.07	.07	.07	.07		.07		.07		.07			.07		

LEM BATTERY CONFIGURATIONS

COMPANY YARDNEY

UNSTAGED — MISSION — "C"

•• PHASE — I-II ••

US-3

		UNIT		CONF. A-1	CONF. A-2		CONF. A-3		CONF. A-4		CONF. A-5			CONF. A-6		
		100%	50%	100%	50%	50%	100%	50%	100%	100%	50%	50%	50%	100%	50%	50%
WEIGHT	CONF. (#)	1290	780	1290	1560		2070		2580		2340			2850		
	WEIGHTED (#)	6579	3978	6579	7956		10,557		13,158		11,934			14,535		
VOLUME (IN^3)		18,020	10,680	18,020	21,360		28,700		36,040		32,040			39,380		
RELIABILITY	R_C			.999	.999999		.999999		.999999		.999999999			.999999999		
	Q_C^{X10-6}			1000	1		1		1		.001			.001		
	R_M^{X10-6}			.999	.998		.999		.999999		.999997			.999998		
	Q_M^{X10-6}			1000	2000		1000		1		3			2		
MERIT	WHR/#	58	56	58	56		56		58		56			56		
	AH/#	2.1	2.0	2.1	2.0		2.0		2.1		2.0			2.0		
	WHR/IN^3	4.1	4.2	4.1	4.2		4.1		4.1		4.2			4.1		
	#/IN^3	0.07	0.07	0.07	0.07		0.07		0.07		0.07			0.07		

[redacted]
MODIFIED HANDLING AUTHORIZED

LEM BATTERY CONFIGURATIONS

COMPANY: EAGLE-PICHER

STAGED – MISSION – "C"

S-1

PHASE: DESCENT : 1 THRU 8
ASCENT : 9 THRU 11

ORIGINAL DATA SHEET		UNIT				CONF. B-1			CONF. B-2			CONF. B-3			CONF. B-4			CONF. B-5			CONF. B-6		
		100 %		50 %		D	A	T	D	A	T	D	A	T	D	A	T	D	A	T	D	A	T
		D	A	D	A	100	100		100 100	100 100		100 50	100 50		50 50	50 50		50 50 50	50 50 50		100	100 50	
WEIGHT	CONF. #	435	230	230	125	435	230	665	870	460	1330	665	355	1020	460	250	710	690	375	1065	435	355	790
	WEIGHTED #	1044	1173	552	638	1044	1173	2217	2088	2346	4434	1596	1811	3407	1104	1276	2380	1656	1914	3570	1044	1811	2855
VOLUME		5050	2880	2880	1500	5050	2880	7930	10100	5760	15860	7930	4380	12310	5760	3000	8760	8640	4500	13140	5050	4380	9430
RELIABILITY	Rc	.986800	.993000	.993000	.996300	–	.993000	–	–	.999951	–	–	.999967	–	–	.999978	–	–	.999999	–	–	.999967	–
	Q_c X10-6	13200	7000	7000	3700	–	7000	–	–	49	–	–	33	–	–	22	–	–	.015	–	–	33	–
	R_M	.986800	.993000	.993000	.996300	X	X	–	–	–	.999778	X	X	–	–	–	.986000	–	–	.999853	X	X	–
	Q_M X10-6	13200	7000	7000	3700	X	X	–	–	–	222	X	X	–	–	–	14000	–	–	147	X	X	–
MERIT	WHR/#	96	86	92	80	96	86		96	86		98	84		92	80		92	80		96	84	
	AH/#	3.4	3.1	3.3	2.9	3.3	3.1		3.4	3.1		3.3	3.0		3.3	2.9		3.3	2.9		3.4	3.0	
	WHR/IN^3	7.5	6.9	7.3	6.7	7.5	6.9		7.5	6.9		7.0	6.8		7.3	6.7		7.3	6.7		7.5	6.8	
	#/IN^3	0.09	0.08	0.08	0.08	0.09	0.08		0.09	0.08		0.08	0.08		0.10	0.08		0.10	0.08		0.09	0.08	

[redacted] MODIFIED HANDLING

LEM BATTERY CONFIGURATIONS

COMPANY: EAGLE-PICHER

STAGED – MISSION – C

S-2

PHASE: DESCENT: 1-8
ASCENT: 9-11

ORIGINAL DATA SHEET		UNIT				CONF. B-7			CONF. B-8			CONF. B-9			CONF. B-10			CONF. B-11			CONF. B-12		
		100 %		50 %		D	A	T	D	A	T	D	A	T	D	A	T	D	A	T	D	A	T
		D	A	D	A	50/50	50/50/50	/	50/50	100/50	/	50	100/50	/	100/50	100/100	/	100	50/50/50	/	50/50	50/50/50	/
WEIGHT	CONF.#	435	230	230	125	460	480	940	460	355	815	230	355	585	665	460	1125	435	460	895	460	375	835
	WEIGHTED #	1044	1173	552	638	1104	2448	3552	1104	1811	2915	5552	1811	2363	1596	2346	3942	1044	2346	3390	1104	1914	3018
VOLUME		5050	2880	2880	1500	5760	5880	11640	5760	4380	10140	2880	4380	7260	7930	5760	13690	5050	5760	10810	5760	4500	10260
RELIABILITY	Rc	.986800	.993000	.993000	.996300	—	.999978 .9993999	—	—	.999967	—	—	.999967	—	—	.999951	—	—	.999951	—	—	.9999999	—
	Q_c X10-6	13200	7000	7000	3700	—	22 .015	—	—	33	—	—	33	—	—	49	—	—	49	—	—	.015	—
	R_M	.986000	.993000	.993000	.996300	—	—	.999858	—	—	.986000	—	—	—	—	—	—	—	—	—	—	—	.986000
	Q_M X10-6	13200	7000	7000	3700	—	—	147	—	—	14000	—	—	—	—	—	—	—	—	—	—	—	14000
MERIT	WHR/#	96	86	92	80	92	86		92	84		92	84		93	86		96	86		92	80	
	AH/#	3.4	3.1	3.3	2.9	3.3	3.1		3.3	3.0		3.3	3.0		3.3	3.1		3.4	3.1		3.3	2.9	
	WHR/IN^3	7.5	6.9	7.3	6.7	7.3	7.0		7.3	6.8		7.3	6.8		7.0	6.9		7.5	6.9		7.3	6.7	
	#/IN^3	0.09	0.08	0.08	0.08	0.08	0.08		0.08	0.08		0.08	0.08		0.08	0.08		0.09	0.08		0.08	0.08	

Contract No. NAS9-1100
Primary Code 008

[redacted] MODIFIED HANDLING AUTHORIZED

GRUMMAN AIRCRAFT ENGINEERING CORPORATION

REPORT LED-390-2
DATE 1 April 1963

[redacted]
MODIFIED HANDLING AUTHORIZED

LEM BATTERY CONFIGURATIONS

COMPANY: ELECTRIC STORAGE BATTERY

STAGED – MISSION – C

PHASE: 1-8 & 9-11

S-3

ORIGINAL DATA SHEET		UNIT				CONF. B-1			CONF. B-2			CONF. B-3			CONF. B-4			CONF. B-5			CONF. B-6		
		100 %		50 %		D	A	T	D	A	T	D	A	T	D	A	T	D	A	T	D	A	T
		D	A	D	A	100%	100%	/	100% 100%	100 100%	/	100 50	100 50	/	50 50	50 50	/	50% 50% 50%	50% 50% 50%	/	100%	100% 50%	/
WEIGHT	CONF. #	619	316	286	145	619	316	935	1238	632	1870	905	461	1366	572	290	862	858	435	1293	619	461	1080
	WEIGHTED #	1475	1618	683	742	1475	1618	3093	2950	3236	6186	2158	2360	6988	1366	1484	2850	2049	2226	4275	1475	2360	3835
VOLUME		10150	6250	5100	2675	10150	6250	16400	20300	12500	32800	15250	8925	24175	10200	5350	15550	15300	8025	23325	10150	8925	19075
RELIABILITY	Rc	.998024	.998024	.998024	.998024		.998024	.998024		.999996	.999996		.999996	.999996		.999996	.999996		.99999999			.999996	.999996
	Q_c X10-6	1976	1976	1976	1976		1976	1976		4	4		4	4		4	4		.01	.01		4	4
	R_M	.998024	.998024	.998024	.998024	.998024	.998024	.996048	.999996	.999996	.999992	.998024	.998024	.996048	.996048	.996048	.992096	.999883	.999883	.99997766	.998024	.998024	.996048
	Q_M X10-6	1976	1976	1976	1976	1976	1976	3952	4	4	8	1976	1976	3952	3952	3952	7904	11.7	11.7	23.4	1976	1976	3952
MERIT	WHR/#	86	86	85	86	86	86		85.8	86		86	86		85	86		85	86		86	86	
	AH/#	3.1	3.1	3.1	3.1	3.1	3.1		3.1	3.1		3.1	3.1		3.1	3.1		3.1	3.1		3.1	3.1	
	WHR/IN3	5.2	4.4	4.8	4.7	5.2	4.4		5.2	4.4		5.1	4.5		4.8	4.7		4.8	4.7		5.2	4.5	
	#/IN3	.06	.05	.06	.05	.06	.05		.06	.05		.06	.05		.06	.05		.06	.05		.06	.05	

[redacted]
MODIFIED HANDLING AUTHORIZED
GRUMMAN AIRCRAFT ENGINEERING CORPORATION

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MODIFIED HANDLING AUTHORIZED

LEM BATTERY CONFIGURATIONS

COMPANY: ELECTRIC STORAGE BATTERY

STAGED – MISSION – "C"

PHASE: 1-8 & 9-11

S-4

ORIGINAL DATA SHEET		UNIT				CONF. B-7			CONF. B-8			CONF. B-9			CONF. B-10			CONF. B-11			CONF. B-12		
		100 %		50 %		D	A	T	D	A	T	D	A	T	D	A	T	D	A	T	D	A	T
		D	A	D	A	50% / 50%	50% / 50%		50% / 50%	100 / 50%		50	100 / 50		100 / 50	100 / 100		100%	100% / 100%		50% / 50%	50% / 50%	
WEIGHT	CONF. #	619	316	286	145	572	576	1,148	572	461	1,033	286	461	747	905	632	1,537	619	632	1,251	572	435	1,007
	WEIGHTED #	1,475	1,618	683	742	1,366	2,946	4,312	1,366	2,360	3,726	683	2,360	3,043	2,158	3,236	5,394	1,475	3,236	4,711	1,366	2,226	3,592
VOLUME		10,150	6,250	5,100	2,675	10,200	10,450	20,650	10,200	8,925	19,125	5,100	8,925	14,025	15,250	12,500	27,750	10,150	12,500	22,650	10,200	8,025	18,225
RELIABILITY	Rc	.998024	.998024	.998024	.998024	-	.999996 / .9999998	-	-	.999996	-	-	.999996	-	-	.999996	-	-	.999996	-	-	.9999999	-
	Q_c X10-6	1976	1976	1976	1976	-	4 / .008	-	-	4	-	-	4	-	-	4	-	-	4	-	-	.01	-
	R_M	.998024	.998024	.998024	.998024	.9999883	.9999883 / .996043	.9999766 / .9960363	.996048	.998024	.994078	.998024	.998024	.996048	.998024	.999996	.998024	.998024	.999996	.99802	.996048	.9999883	.9960363
	Q_M X10-6	1976	1976	1976	1976	11.7	11.7 / 3952	23.4 / 2965.7	3952	1976	5928	1976	1976	3952	1976	4	1980	1976	4	1980	3952	11.7	3963.7
MERIT	WHR/#	86	86	85	86	85	86		85	86		85	86		86	86		86	86		85	86	
	AH/#	3.1	3.1	3.1	3.1	3.1	3.1		3.1	3.1		3.1	3.1		3.1	3.1		3.1	3.1		3.1	3.1	
	WHR/IN³	5.2	4.4	4.8	4.7	4.8	4.7		4.8	4.5		4.8	4.5		5.1	4.4		5.2	4.4		4.8	4.7	
	#/IN³	.06	.05	.06	.05	.06	.06		.06	.05		.06	.05		.06	.05		.06	.05		.06	.05	

[redacted] MODIFIED HANDLING AUTHORIZED

LEM BATTERY CONFIGURATIONS

COMPANY: YARDNEY ELEC

STAGED – MISSION – "C"

S-5

PHASE: DESCENT : 1 THRU 8
ASCENT : 9 THRU 11

ORIGINAL DATA SHEET		UNIT				CONF. B-1			CONF. B-2			CONF. B-3			CONF. B-4			CONF. B-5			CONF. B-6		
		100 %		50 %		D	A	T	D	A	T	D	A	T	D	A	T	D	A	T	D	A	T
		D	A	D	A	100	100	/	100 100	100 100	/	100 50	100 50	/	50 50	50 50	/	50 50 50	50 50 50	/	100	100 50	/
WEIGHT	CONF. #	860	400	435	200	860	400	1260	1720	800	2520	1295	600	1895	870	400	1270	1305	600	1905	860	600	1460
	WEIGHTED #	2065	2040	1044	1020	2065	2040	4105	4130	4080	8210	3109	3060	6169	2088	2040	4128	3132	3060	6192	2065	3060	5125
VOLUME		12013	5801	6145	3350	12013	5801	17814	24026	11602	35628	18158	9151	27309	12290	6700	18990	18435	10050	28485	12013	9151	21164
RELIABILITY	Rc																						
	Qc^{X10-6}																						
	RM																						
	QM^{X10-6}																						
MERIT	WHR/#	58	60	57	60	58	60		58	60		58	59		57	60		57	60		58	59	
	AH/#	2.1	2.1	2.0	2.1	2.1	2.1		2.1	2.1		2.1	2.0		2.0	2.1		2.0	2.1		2.1	2.0	
	WHR/IN^3	4.2	4.1	4.1	3.6	4.2	4.1		4.2	4.1		4.1	3.8		4.1	3.6		4.1	3.6		4.2	3.8	
	$\#/IN^3$	0.07	0.07	0.07	0.06	0.07	0.07		0.07	0.07		0.07	0.07		0.07	0.06		0.07	0.06		0.07	0.07	

[redacted]
MODIFIED HANDLING AUTHORIZED

LEM BATTERY CONFIGURATIONS

COMPANY: YARDNEY ELEC

STAGED – MISSION – "C"

PHASE: DESCENT : 1 THRU 8
ASCENT : 9 THRU 11

S-6

ORIGINAL DATA SHEET		UNIT 100% D	UNIT 100% A	UNIT 50% D	UNIT 50% A	CONF. B-7 D	CONF. B-7 A	CONF. B-7 T	CONF. B-8 D	CONF. B-8 A	CONF. B-8 T	CONF. B-9 D	CONF. B-9 A	CONF. B-9 T	CONF. B-10 D	CONF. B-10 A	CONF. B-10 T	CONF. B-11 D	CONF. B-11 A	CONF. B-11 T	CONF. B-12 D	CONF. B-12 A	CONF. B-12 T
						50 / 50	50 / 50	/	50 / 50	100 / 50	/	50	100 / 50	/	100 / 50	100 / 100	/	100	100 / 100	/	50 / 50	50 / 50	/
WEIGHT	CONF. #	860	400	435	200	870	835	1705	870	600	1470	435	600	1035	1295	800	2095	860	800	1660	870	600	1470
	WEIGHTED #	2065	2040	1044	1020	2088	4258	6346	2088	3060	5148	1044	3060	4104	3109	4080	7189	2065	4080	6145	2088	3060	5148
VOLUME	IN³	12013	5801	6145	3350	12290	12845	25135	12290	9151	21441	6145	9151	15296	18158	11602	29760	12013	11602	23615	12290	10050	22340
RELIABILITY	Rc																						
	Qc X10-6																						
	RM																						
	QM X10-6																						
MERIT	WHR/#	58	60	57	60	57	58		57	59		57	59		58	59		58	60		57	60	
	AH/#	2.1	2.1	2.0	2.1	2.0	2.1		2.0	2.0		2.0	2.0		2.1	2.0		2.1	2.1		2.0	2.1	
	WHR/IN³	4.8	4.1	4.1	3.6	4.1	3.7		4.1	3.8		4.1	3.8		4.1	3.8		4.2	4.1		4.1	3.6	
	#/IN³	0.07	0.07	0.07	0.06	0.07	0.07		0.07	0.07		0.07	0.07		0.07	0.07		0.07	0.07		0.07	0.06	

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SUMMARY SHEET (S-7) LEM BATTERY EVALUATION

MISSION "C" PHASES 1 THRU 8 AND 9 THRU 11

BASED ON FIGURES ORIGINALLY RECEIVED

	CONFIGURATION B-2									CONFIGURATION B-5								
	DESCENT 100 100			ASCENT 100 100						DESCENT 50 50 50			ASCENT 50 50 50					
	E - P			E S B			YARD			E - P			E S B			YARD		
	DES	ASC	T	DES	ASC	T	DES	ASC	T	DES	ASC	T	DES	ASC	T	DES	ASC	T
WEIGHT	870	460	1330	1238	632	1870	1720	800	2520	690	375	1065	858	435	1293	1305	600	1905
WEIGHTED WEIGHT	2088	2346	4434	2950	3236	6186	4130	4080	8210	1656	1912	3568	2049	2226	4275	3132	3060	6192
VOLUME IN^3	10,100	5760	15860	20300	12500	32800	24026	11602	35628	8640	4500	13140	15300	8025	23325	18435	10050	28485
RELIABILITY R_C		.999951			.9999996						.9999999			.999999999				
RELIABILITY Q_C		49			0.473						0.115			.000975				
RELIABILITY R_M			.999778			.9999966						.999853			.9999949			
RELIABILITY Q_M			222			2.17						147			5.1			
MW W-HRS/LB	97	86		86	86		58	60		92	80		85	86		57	60	
MW A-H/LB	3.5	3.1		3.1	3.1		2.1	2.1		3.3	2.9		3.1	3.1		2.0	2.1	
MV W-H/IN^3	8.3	6.8		5.2	4.4		4.2	4.1		7.3	6.7		4.8	4.7		4.1	3.6	
MD LB/IN3	0.09	0.08		.06	.05		0.07	0.07		0.08	0.08		0.06	0.05		0.07	0.06	

	CONFIGURATION B-7									CONFIGURATION B-12								
	DESCENT 50 50			ASCENT 50 50 50 * DESCENT SIZE 7						DESCENT 50 50			ASCENT 50 50 50					
	E - P			E S B			YARD			E - P			E S B			YARD		
	DES	ASC	T	DES	ASC	T	DES	ASC	T	DES	ASC	T	DES	ASC	T	DES	ASC	T
WEIGHT	460	480	940	572	576	1148	870	835	1705	460	375	835	572	435	1007	870	600	1470
WEIGHTED WEIGHT	1104	2248	3552	1366	2946	4312	2088	4258	6346	1104	1912	3016	1366	2226	3592	2088	3060	5148
VOLUME IN^3	5760	5880	11640	10200	10450	20650	12290	12845	25135	5760	4500	10260	10200	8025	18225	12290	10050	22340
RELIABILITY R_C		.999967			.9999998						.9999969			.999999999				
RELIABILITY Q_C		33			0.473						3.105			.000975				
RELIABILITY R_M			.999853			.9999949						.986			.997390			
RELIABILITY Q_M			147			5.1						14000			2610			
MW W-HRS/LB	92	85		85	86		57	58		92	80		85	86		57	60	
MW A-H/LB	3.2	3.0		3.1	3.1		2.0	2.1		3.2	2.8		3.1	3.1		2.0	2.1	
MV W-H/IN^3	7.3	7.0		4.8	4.7		4.1	3.9		7.3	6.7		4.8	4.7		4.1	3.6	
MD LB/IN3	0.08	0.08		.06	.06		0.07	0.07		0.08	0.08		.06	.05		0.07	0.06	

[redacted]

MODIFIED HANDLING AUTHORIZED

SUMMARY SHEET (S-8) CONFIGURATION B-5 LEM BATTERY EVALUATION

BASED ON FIGURES ORIGINALLY RECEIVED	MISSION "A" 1-8 9-11 CONFIGURATION "B5" DESCENT 50 50 50 ASCENT 50 50 50									MISSION "B" 1-8 9-11 CONFIGURATION B-5 DESCENT 50 50 50 ASCENT 50 50 50									MISSION "C" 1-8 9-11 CONFIGURATION "B-5" DESCENT 50 50 50 ASCENT 50 50 50								
	E - P			E S B			YARD.			E - P			E S B			YARD.			E - P			E S B			YARD.		
	DES.	ASC.	TOTAL	DES.	ASC.	TOTAL	DES.	ASC.	TOTAL	DES.	ASC.	TOTAL	DES.	ASC.	TOTAL	DES.	ASC.	TOTAL	DES.	ASC.	TOTAL	DES.	ASC.	TOTAL	DES.	ASC.	TOTAL
WEIGHT	810	195	1005	1050	180	1230	1575	285	1860	765	285	1050	927	315	1242	1440	450	1890	690	375	1065	858	435	1293	1305	600	1905
WEIGHTED WEIGHT	1944	994	2938	2520	918	3438	3780	1453	5233	1836	1453	3289	2225	1606	3831	3456	2295	5751	1656	1912	3568	2059	2218	4277	3132	3060	6192
VOLUME IN^3	9900	2100	12000	16230	3690	19920	22050	4515	26565	9450	3150	12600	15000	5265	20265	19962	7200	27162	8640	4500	13140	15300	8025	23325	18135	10050	28485
RELIABILITY R_C		.9999999			.999999999						.9999999			.999999999						.9999999			.999999999				
RELIABILITY Q_C		0.115			.000975						0.115			.000975						0.115			.000975				
RELIABILITY R_M			.999853			.9999949						.999853			.9999949						.999853			.9999949			
RELIABILITY Q_M			147			5.1						147			5.1						147			5.1			
Mw W-HRS/LB	91	87		85	80		57	48		90	91		87	86		57	55		89	80		85	86		57	60	
Mw A-H/LB	3.2	3.1		3.0	2.8		2.0	1.7		3.2	3.2		3.1	3.1		2.0	2.0		3.2	2.9		3.1	3.1		2.0	2.1	
Mv W-H/IN^3	7.4	8.1		5.5	3.9		4.0	3.0		7.3	8.3		5.4	5.1		4.1	3.5		7.1	6.7		4.8	4.7		4.1	3.6	
MD LB/IN^3	.08	.09		0.06	0.05		0.08	0.06		0.08	0.09		0.06	0.06		0.07	0.06		0.08	0.08		0.06	0.05		0.07	0.07	

[redacted]
MODIFIED HANDLING

SUMMARY SHEET (S-9) — LEM BATTERY EVALUATION

SECONDARY BAT BASED ON REVISED FIGURES

	MISSION "A" CONFIGURATION "B5" DESCENT 50 50 50 ASCENT 50 50 50									MISSION "B" CONFIGURATION B-5 DESCENT 50 90 50 ASCENT 50 50 50									MISSION "C" CONFIGURATION "B-5" DESCENT 50 50 50 ASCENT 50 50 50								
	E - P			E S B			YARD.			E - P			E S B			YARD.			E - P			E S B			YARD.		
	DES.	ASC.	TOTAL	DES.	ASC.	TOTAL	DES.	ASC.	TOTAL	DES.	ASC.	TOTAL	DES.	ASC.	TOTAL	DES.	ASC.	TOTAL	DES.	ASC.	TOTAL	DES.	ASC.	TOTAL	DES.	ASC.	TOTAL
WEIGHT	1050	270	1320	1050	180	1230	960	195	1155	960	360	1320	927	315	1242	900	300	1200	826	480	1306	858	435	1293	810	420	1230
WEIGHTED WEIGHT	2520	1375	3895	2520	610	3130	2310	995	3305	2310	1830	4140	2220	1605	3825	2160	1530	4090	1980	2440	4420	2049	2226	4275	1940	2140	4080
VOLUME IN ^{3}	11,000	2,150	13,150	13,900	3,160	17,100	11,700	2,490	14,190	10,000	3,320	13,320	12,900	4,500	17,200	10,800	3,960	14,760	8,640	4,500	13,140	13,100	6,850	20,000	9,750	5,040	1,479
RELIABILITY R_C		.999999989	.99999989		.99999999	.99999999		.999999999	.999999999		.99999989	.99999989		.99999999	.99999999		.999999999	.999999999		.99999989	.99999989		.99999999	.99999999		.999999999	.999999999
RELIABILITY Q_C		0.115	0.115		0.01	0.01		0.001	0.001		0.115	0.115		0.01	0.01		0.001	0.001		0.115	0.115		0.01	0.01		0.001	0.001
RELIABILITY R_M			.999853			.9999766			.999994			.999853			.9999766			.999994			.999853			.9999766			.999994
RELIABILITY Q_M			147			23.4			6			147			23.4			6			147			23.4			6
MW W-HRS/LB	82	56		85	80		85	65		82	70		87	86		85	75		82	76		85	86		85	80	
MW A-H/LB	2.5	1.5		3.0	2.8		3.0	2.3		2.5	2.0		3.1	3.1		3.0	2.7		2.6	2.3		3.0	3.1		3.0	2.9	
MV W-H/IN^3	7.3	5.3		6.5	4.6		7.0	5.0		7.3	6.1		5.4	5.1		7.0	5.8		7.3	6.7		5.4	5.3		7.0	6.4	
MD LB/IN^3	0.10	0.12		0.07	0.06		0.08	0.08		0.10	0.11		0.06	0.06		0.08	0.08		0.10	0.11		0.07	0.06		0.08	0.08	

[redacted]
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SUMMARY SHEET S-10 LEM BATTERY EVALUATION

PHASES 1-B, 9-11 PLUS 1.5 HOURS OF PHASE 8

CONFIGURATION "B-5"
DESCENT 50 50 50 ASCENT 50 50 50

GRUMMANS ESTIMATE (SECONDARY BAT.)		SINGLE 50% BATTERY VALUES						MISSION "A"			MISSION "B"			MISSION "C"		
		MISSION "A"		MISSION "B"		MISSION "C"		49.46 KWHR DESCENT	9.14 KWHR ASCENT	TOTAL	45.57 KWHR DESCENT	15.2 KWHR ASCENT	TOTAL	41.56 KWHR DESCENT	21.36 KWHR ASCENT	TOTAL
		DES.	ASC.	DES.	ASC.	DES.	ASC.									
KWHR →		24.7	4.6	22.8	7.6	20.8	10.7									
WEIGHT		291	76	269	109	244	133	873	228	1101	805	327	1132	732	399	1131
WEIGHTED WEIGHT		697	387	645	556	585	680	2090	1165	3255	1930	1665	3595	1750	2040	3790
VOLUME IN^3		3130	673	2880	1165	2560	1385	9390	2019	11409	8640	3495	12135	7680	4155	11835
RELIABILITY	R_C	0.999250	0.999612	0.999250	0.999612	0.999250	0.999612		0.99999999	0.99999999		0.99999999	0.99999999		0.99999999	0.99999999
	Q_C								0.01	0.01		0.01	0.01		0.01	0.01
	R_M	0.999250	0.999612	0.999250	0.999612	0.999250	0.999612	0.999700	0.99999999	0.999700	0.999700	0.99999999	0.999700	0.999700	0.99999999	0.999700
	Q_M							300	0.01	300	300	0.01	300	300	0.01	300
MW	WATT-HOURS/LB	85	60	85	70	85	80									
MV	WATT-HOURS/IN^3	8	5.5	8	6.0	8	6.5									

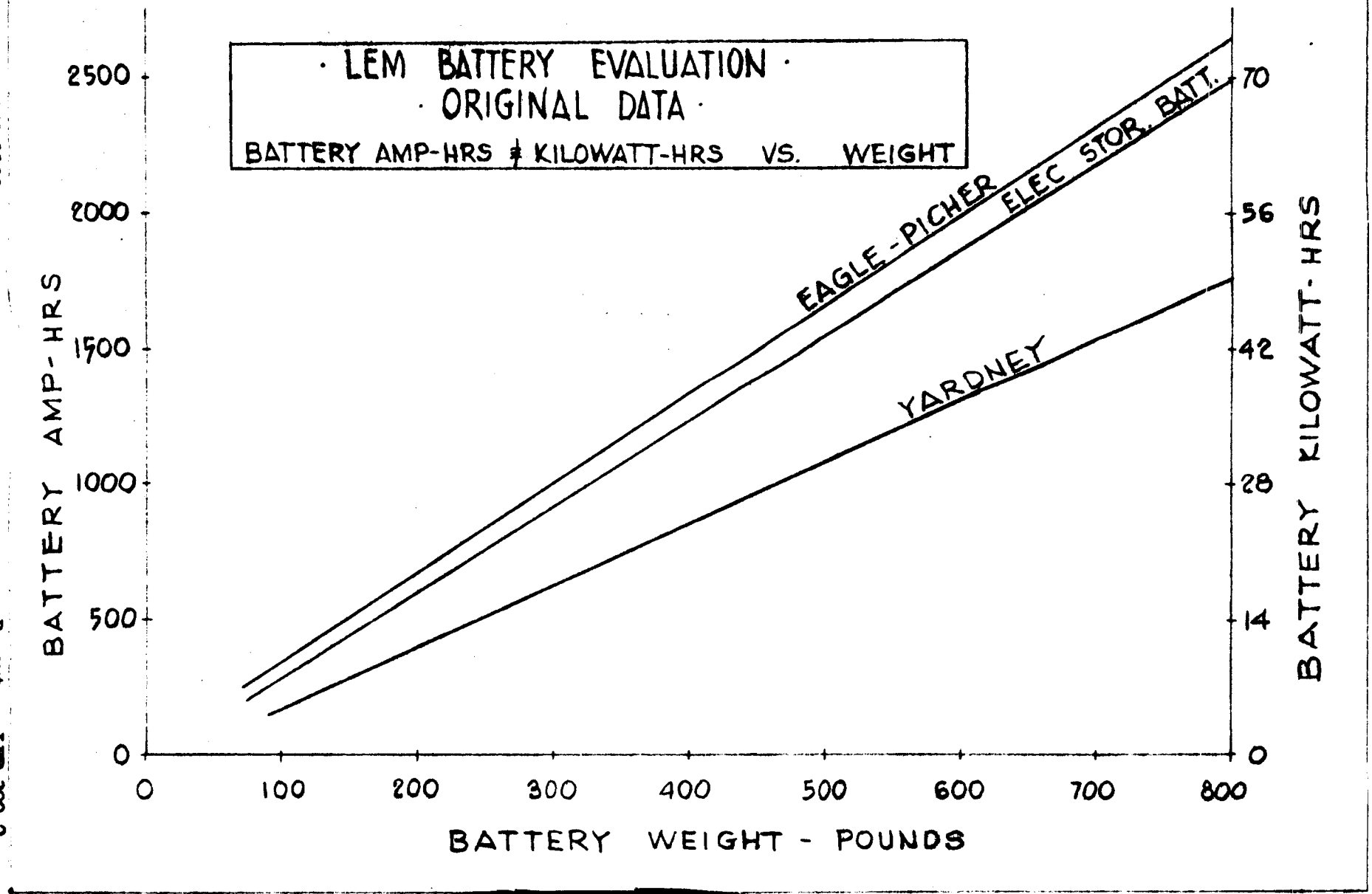
MODIFIED HANDLING AUTHORIZED

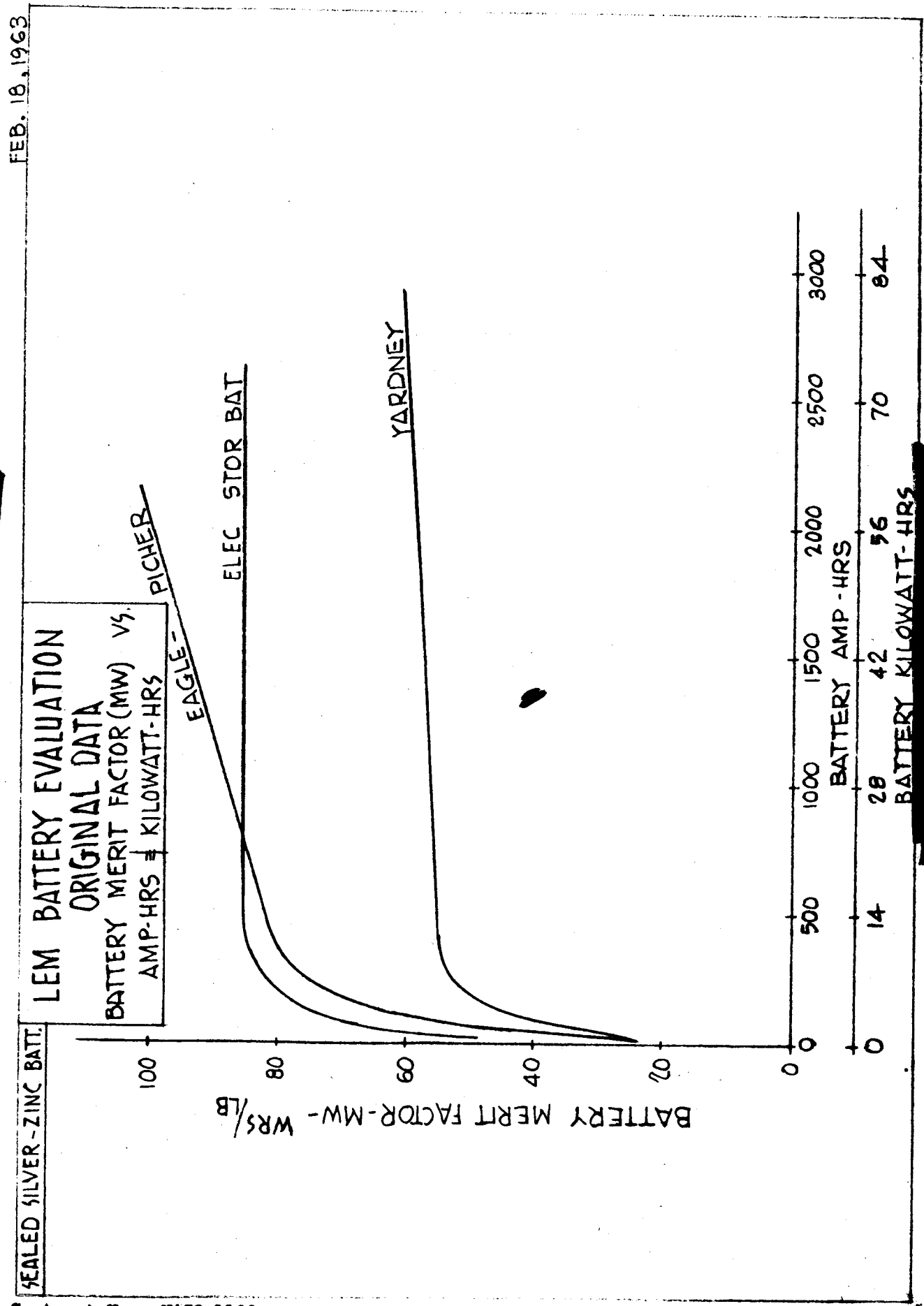
SUMMARY SHEET (P-1) LEM BATTERY EVALUATION
PEAKING BATTERY • PHASE 2-11

	CONFIGURATION C-1			CONFIGURATION C-2			CONFIGURATION C-3		
	100			50		50	50	50	50
	E-P	ESB	YARD.	E-P	ESB	YARD.	E-P	ESB	YARD.
WEIGHT	29	21	42	38	25	44	57	38	66
WEIGHTED WEIGHT	148	109	214	194	130	224	291	194	337
VOLUME IN^3	378	568	770	410	1030	986	616	1545	1479
RELIABILITY R_C	.997	.998695		.999991	.9999983		.99999998	.99999999	
RELIABILITY Q_C $X10^{-6}$	3000	1300		9	1.7		.027	.00221	
RELIABILITY R_M	.997	.998695		.994	.9974		.999973	.9999949	
RELIABILITY Q_M $X10^{-6}$	3000	1300		6000	2600		27	5.1	
MW W-HRS/LB	30.4	48.4	28	22.7	48.4	27	22.7	48.4	27
MW A-H/LB	1.1	1.7	1.0	0.8	1.3	1.0	0.8	1.3	1.0
MV W-H/IN^3	2.3	1.8	1.6	2.1	1.0	1.2	2.1	1.0	1.2
MD LB/IN^3	.08	.04	.05	.09	.02	.04	.09	.02	.04

MODIFIED HANDLING AUTHORIZED
GRUMMAN AIRCRAFT ENGINEERING CORPORATION

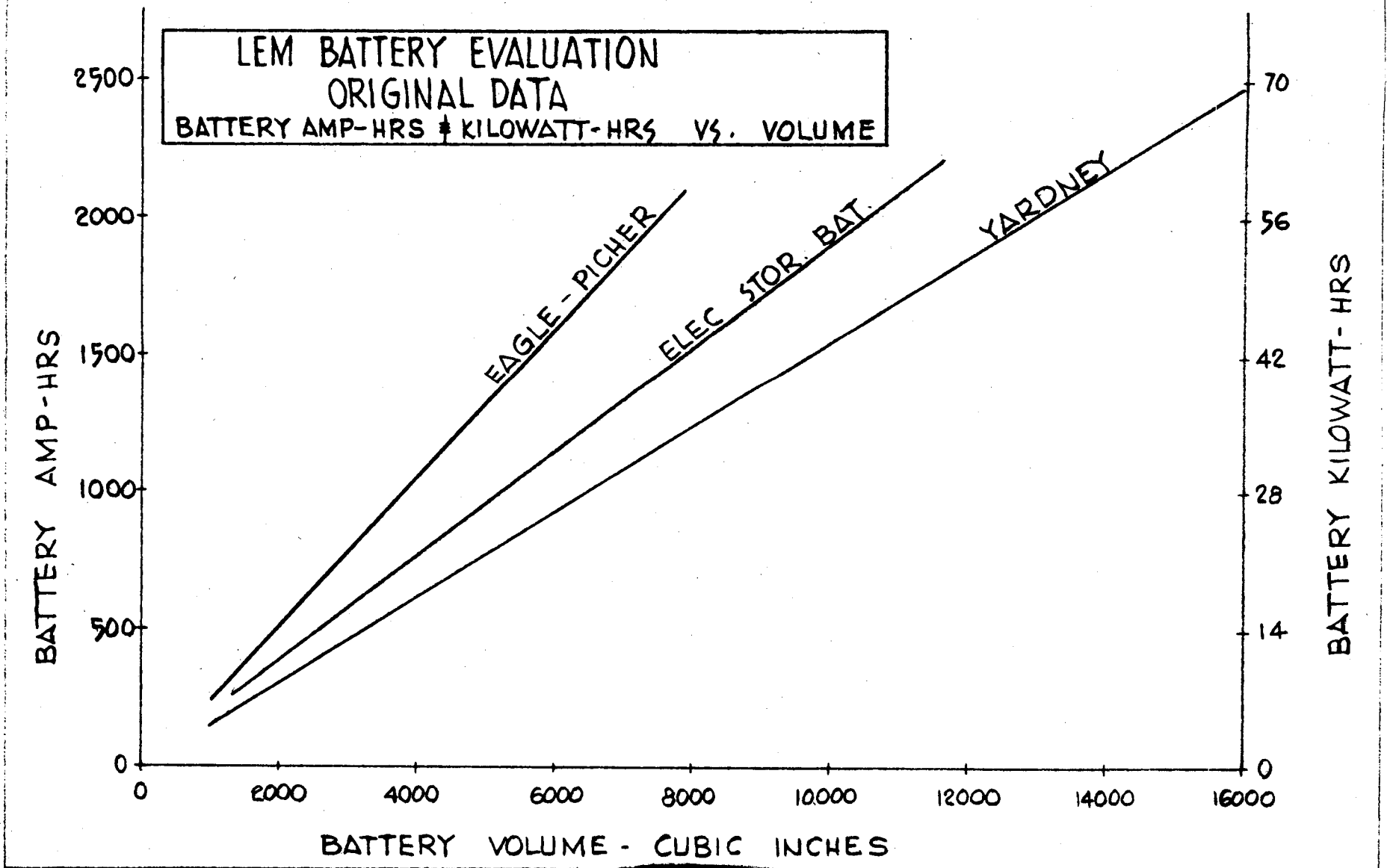
SEALED SILVER ZINC BATTERY




FEB. 18, 1963
SEALED SILVER-ZINC BATT.
LEM BATTERY EVALUATION
ORIGINAL DATA
BATTERY MERIT FACTOR (MW) VS.
AMP-HRS & KILOWATT-HRS
EAGLE-PICHER
ELEC STOR BAT
YARDNEY
BATTERY MERIT FACTOR-MW-HRS/LB
100
80
60
40
20
0
0
500
1000
1500
2000
2500
3000
BATTERY AMP-HRS
0
14
28
42
56
70
84
BATTERY KILOWATT-HRS
GRUMMAN AIRCRAFT ENGINEERING CORPORATION

FEB. 18 - 1963

SEALED SILVER ZINC BATTERY



GRUMMAN AIRCRAFT ENGINEERING CORPORATION

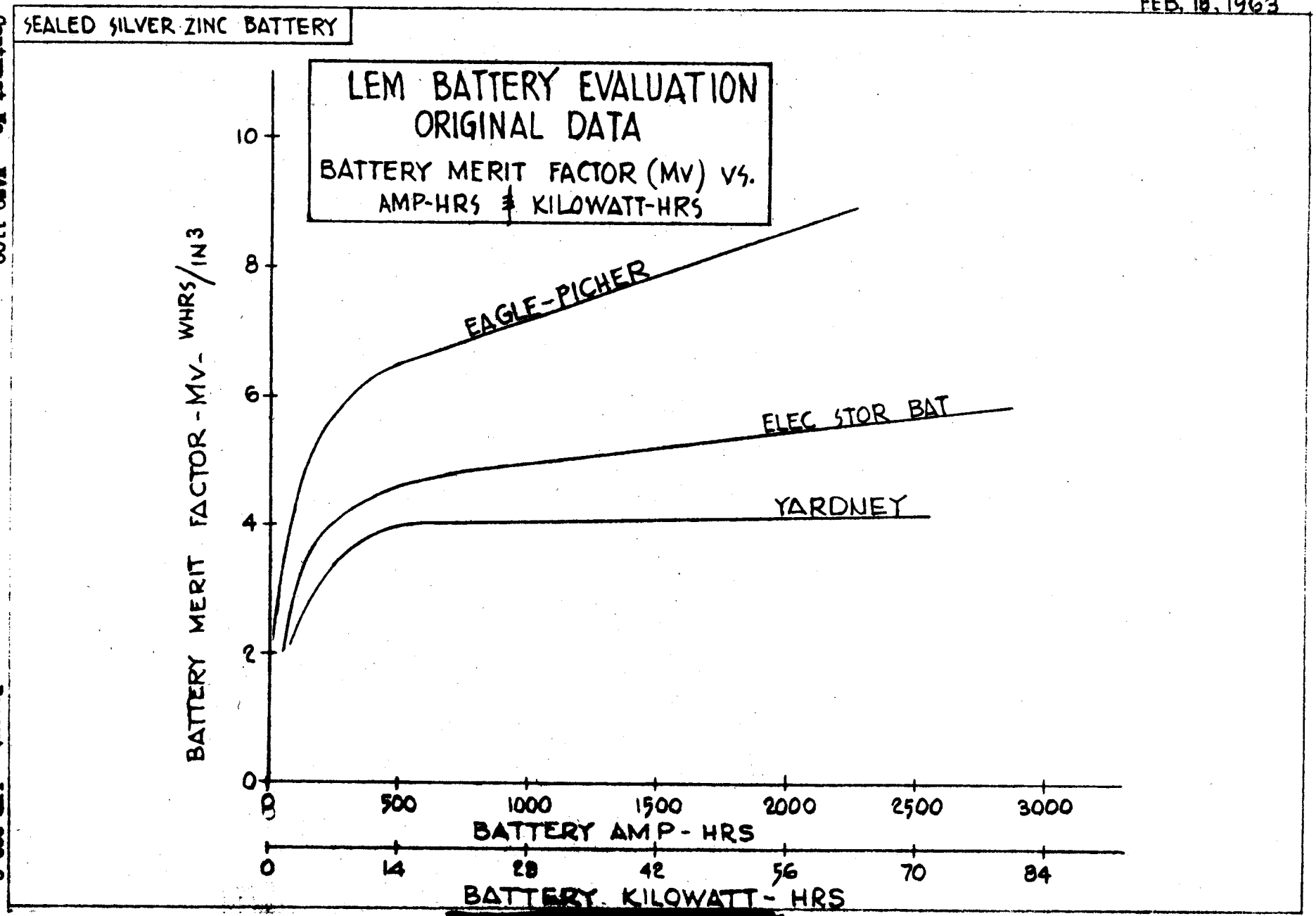
[redacted]

FEB. 18, 1963

SEALED SILVER ZINC BATTERY

Contract No. NAS9-1100
Primary Code 008

Report LMP-360-2
Date 1 April 1963



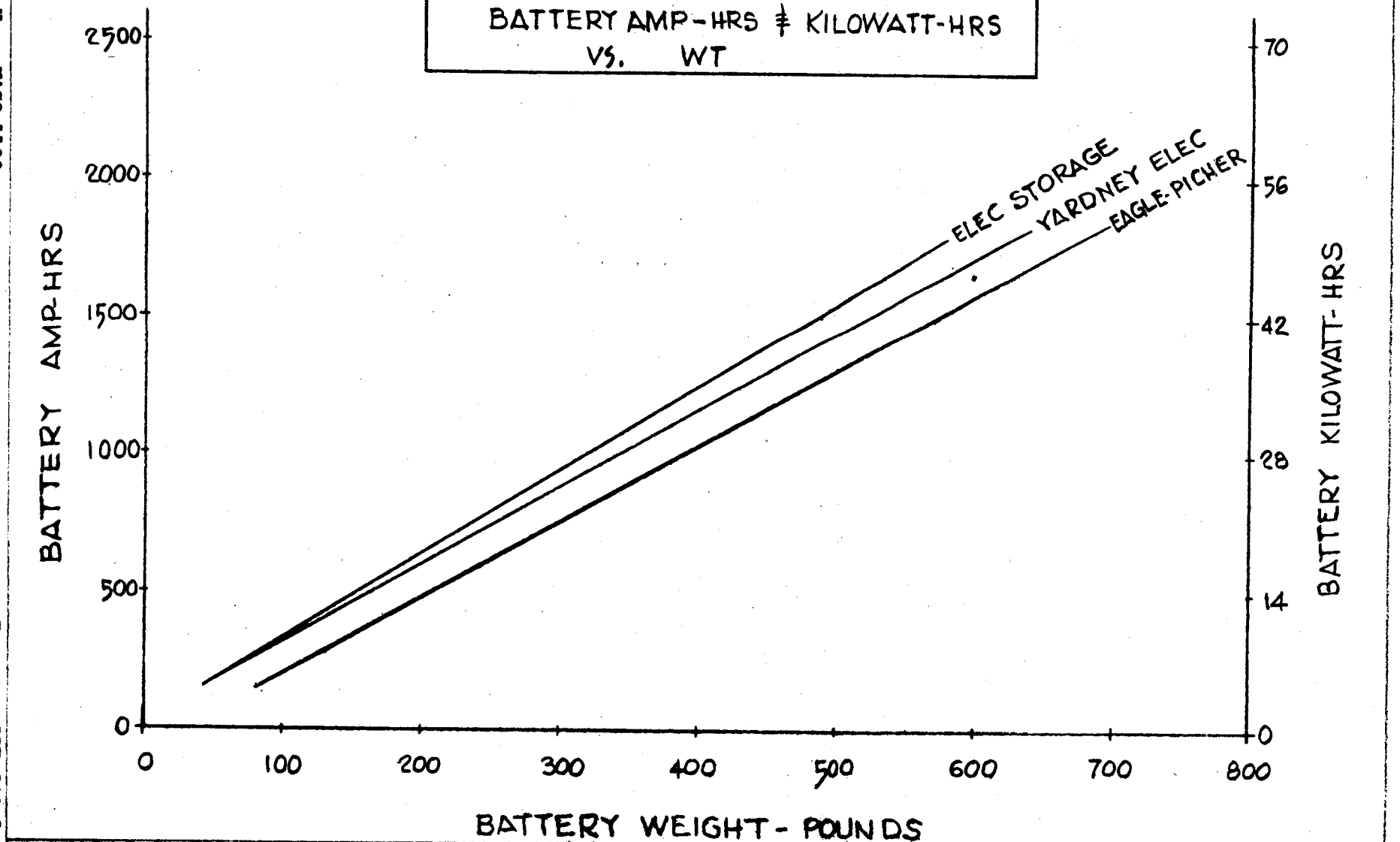
[redacted]

GRUMMAN AIRCRAFT ENGINEERING CORPORATION

PAGE G-4

SEALED SILVER-ZINC BATTERY

LEM BATTERY EVALUATION
REVISED DATA - SECONDARY BATTERY
BATTERY AMP-HRS & KILOWATT-HRS VS. WT

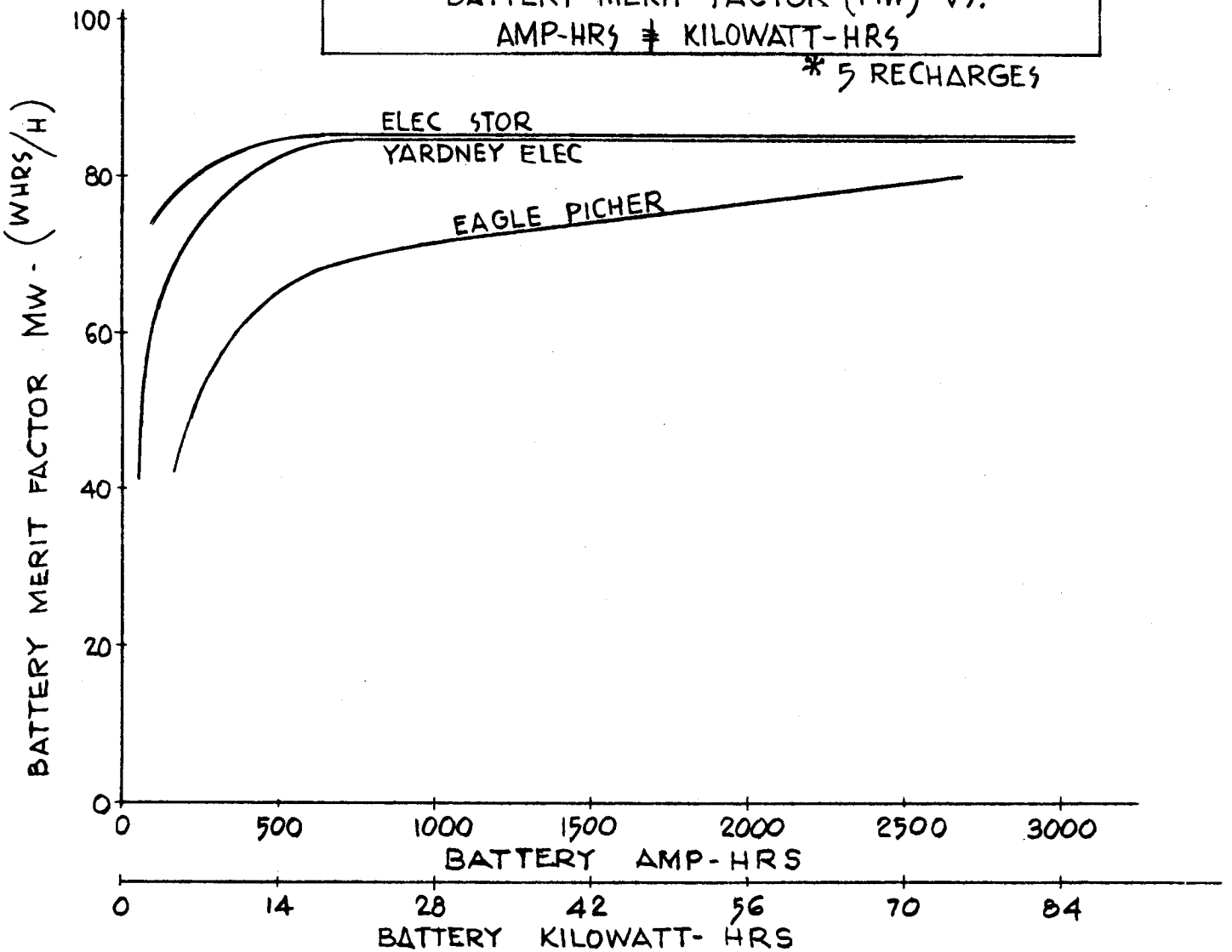


[redacted]

GRUMMAN AIRCRAFT ENGINEERING CORPORATION

SEALED SILVER-ZINC BATTERY

LEM BATTERY EVALUATION
REVISED DATA- SECONDARY BATTERY *
BATTERY MERIT FACTOR (Mw) VS.
AMP-HRS & KILOWATT-HRS
* 5 RECHARGES



GRUMMAN AIRCRAFT ENGINEERING CORPORATION

Contract No. NAS9-1100
Primary Code 008

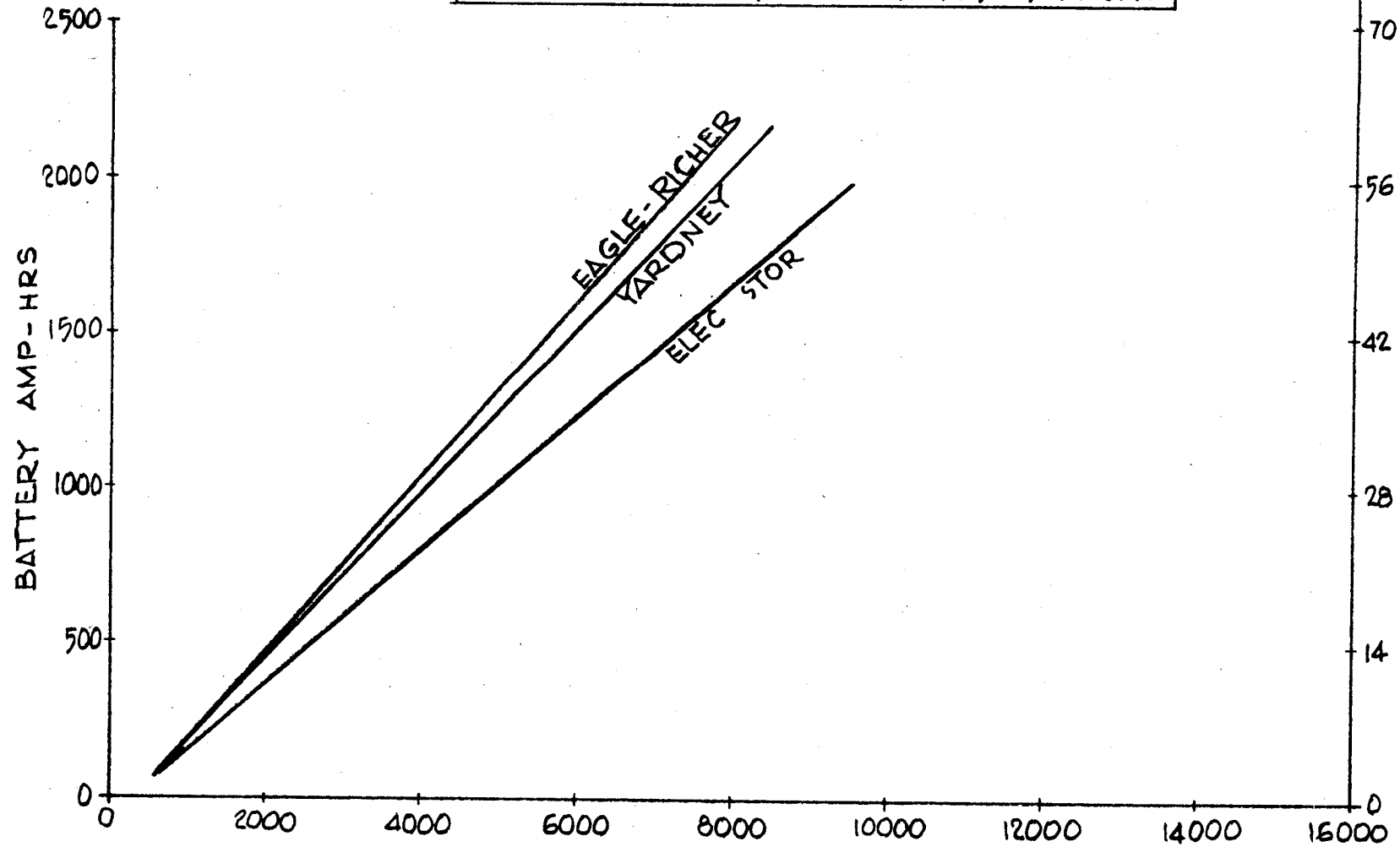
Report LED-390-2
Date 1 April 1963

[redacted] N [redacted]

FEB. 21 - 1963

SEALED SILVER ZINC BATTERY

LEM BATTERY EVALUATION
REVISED DATA - SECONDARY BATTERY
BATTERY AMP-HR & KILOWATT-HRS VS. VOLUME



Contract No. NAS9-1100
Primary Code 008

Report LED-390-2
Date 1 April 1963

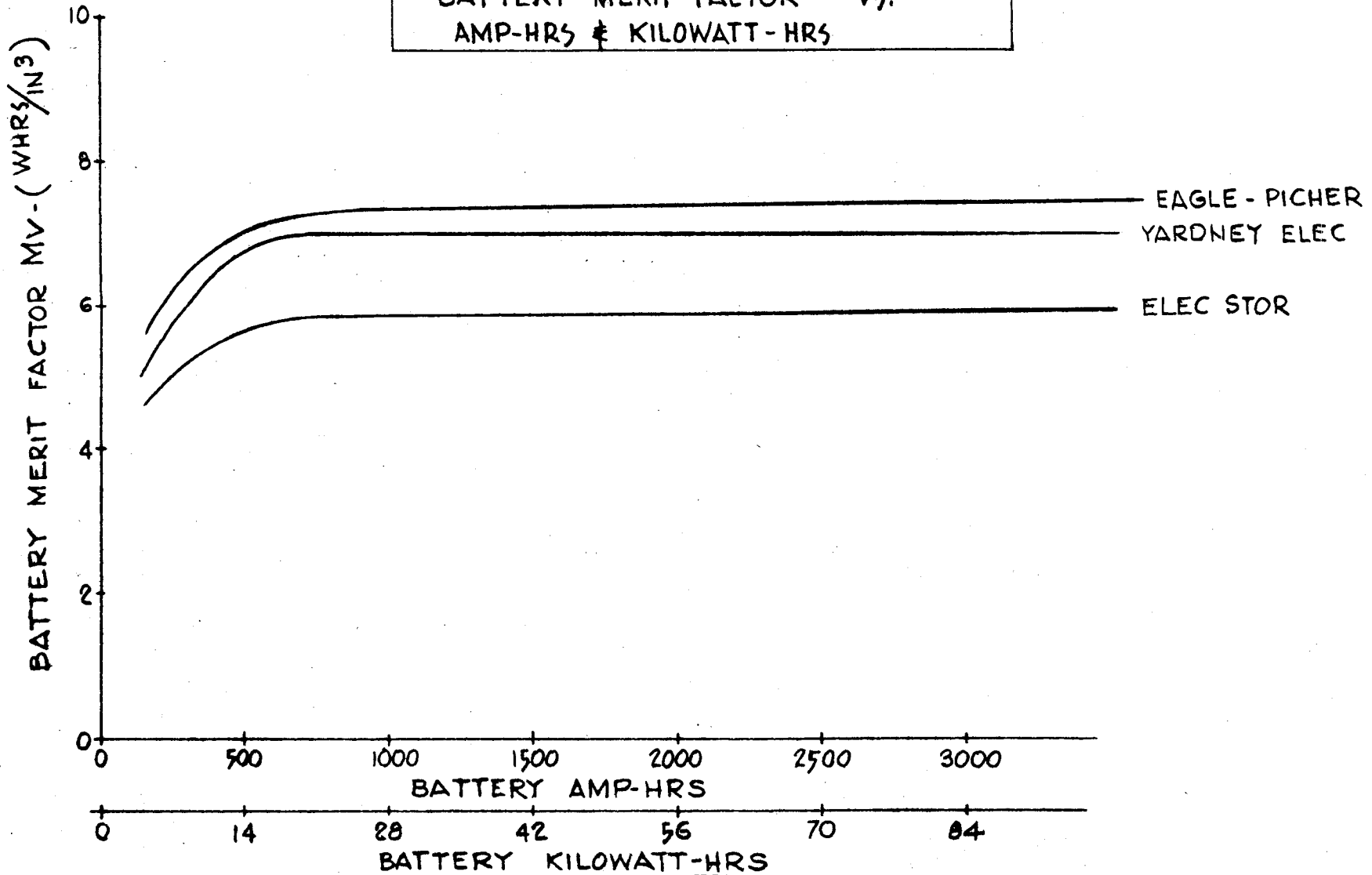
[redacted]

GRUMMAN AIRCRAFT ENGINEERING CORPORATION

FEB. 21, 1968

SEALED SILVER-ZINC BATTERY

LEM BATTERY EVALUATION
REVISED DATA-SECONDARY BATTERY
BATTERY MERIT FACTOR VS. AMP-HRS & KILOWATT-HRS



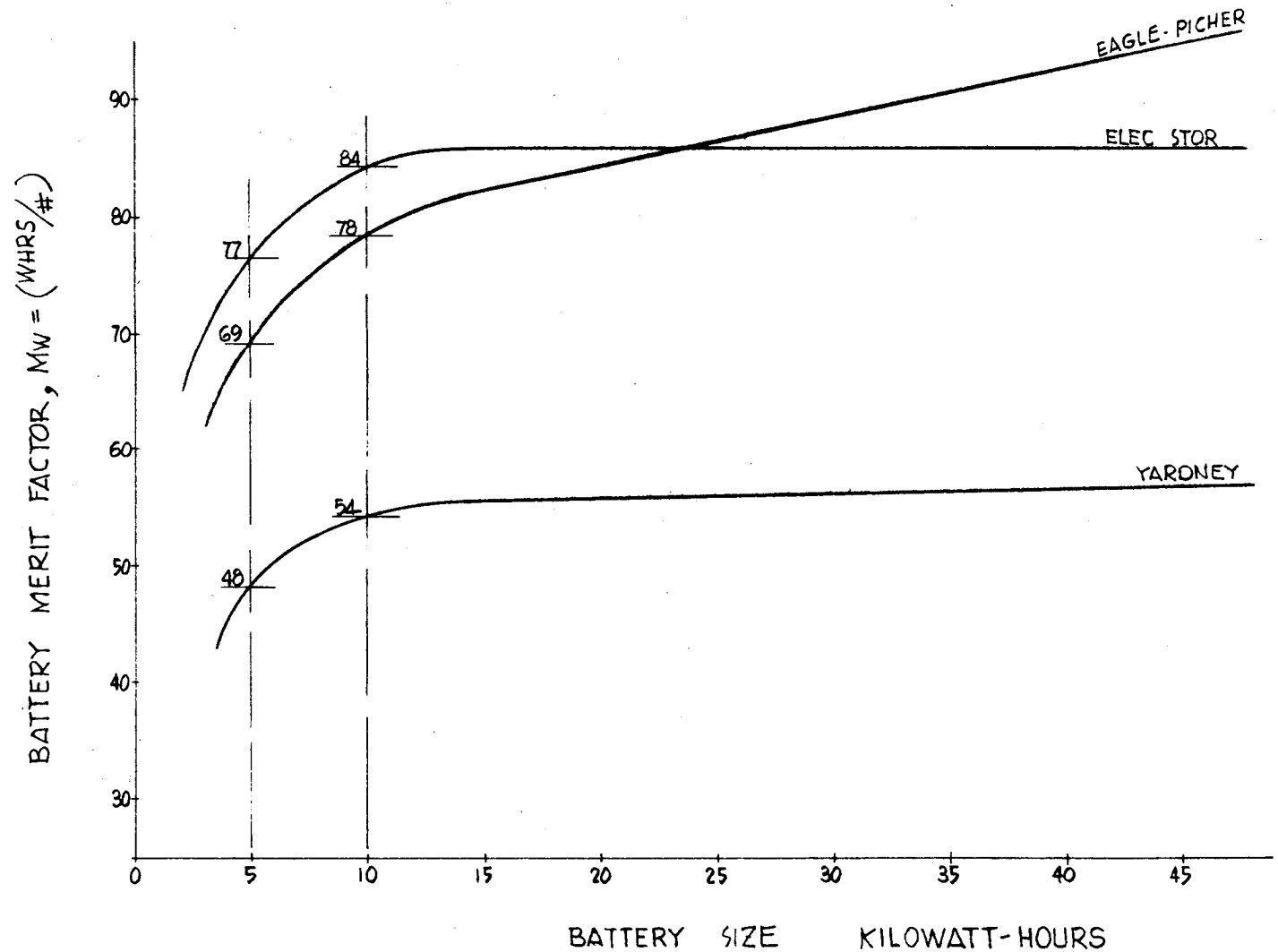
Contract No. NAS9-1100
Primary Code 008

Report LMD-390-2
Date 1 April 1963

GRUMMAN AIRCRAFT ENGINEERING CORPORATION

MASTER

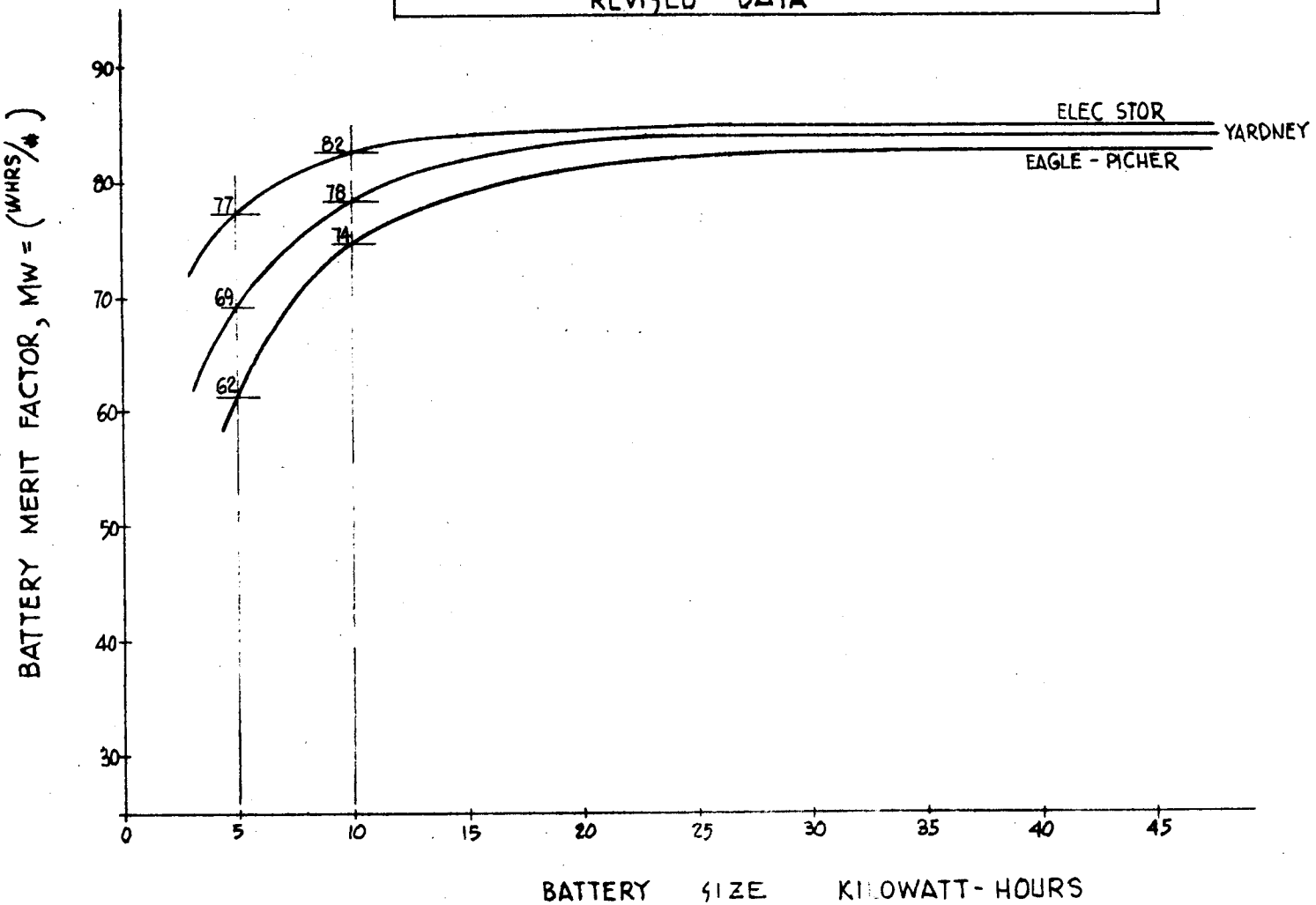
LEM BATTERY EVALUATION
BATTERY MERIT FACTOR (Mw) vs. KILOWATT-HOURS
ORIGINAL DATA



[redacted]

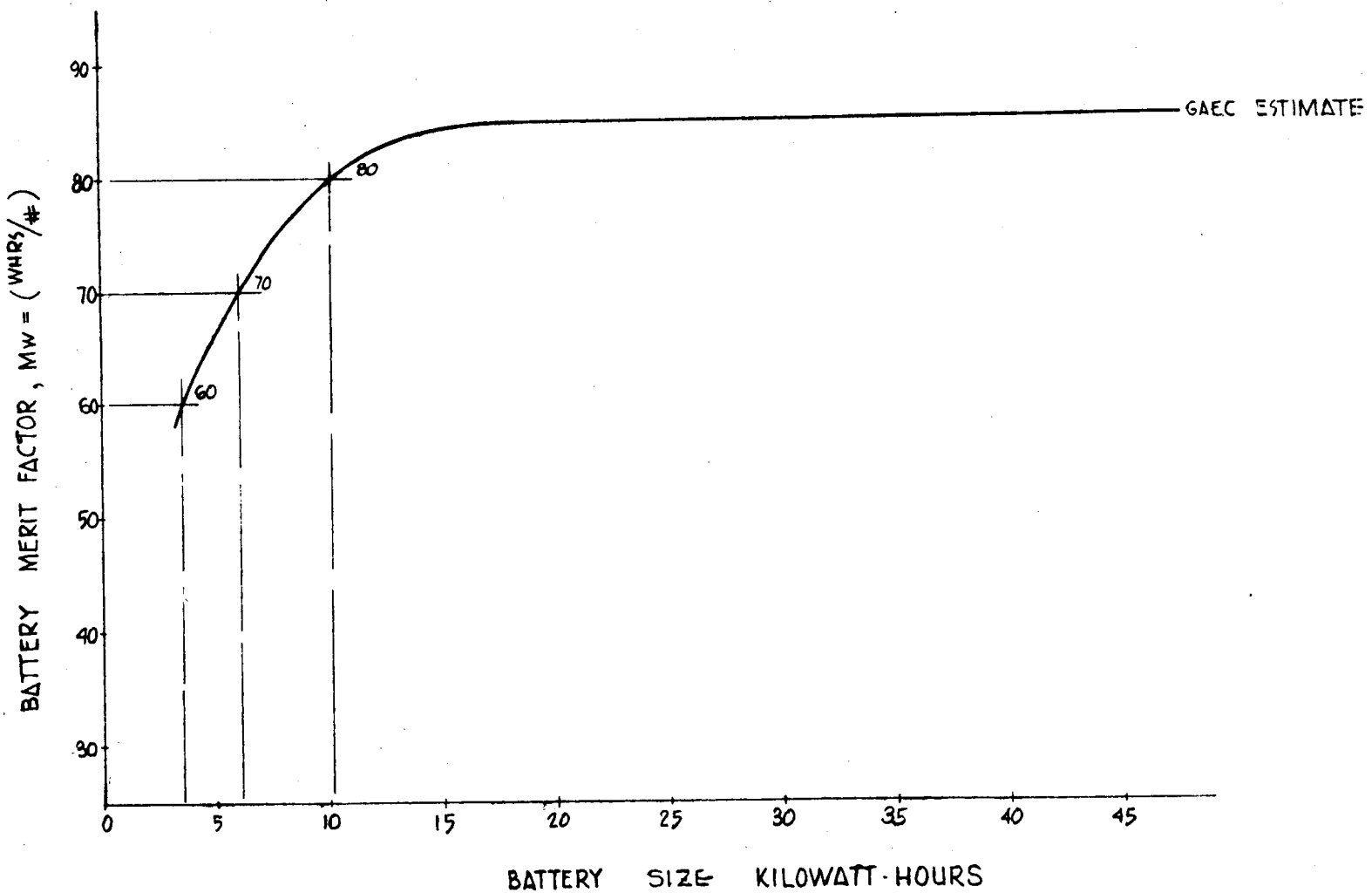
MASTER

LEM BATTERY EVALUATION
BATTERY MERIT FACTOR (Mw) VS. KILOWATT-HRS
REVISED DATA



MASTER

LEM BATTERY EVALUATION
BATTERY MERIT FACTOR (Mw) vs. KILOWATT HOURS



SECTION V - POWER GENERATION

Introduction

1. The LEM Power Generation Section configuration study was initiated by the issuance of a Technical Information Request (TIR), reference 1, to five possible manufacturers of energy conversion units. These companies were:

   (a) Allis Chalmers Company
   (b) General Electric Company
   (c) Pratt and Whitney Aircraft
   (d) Sundstrand Aviation
   (e) Tapco Group of TRW*

   The TIR defined the basic Power Generation Section of the Electrical Power Subsystem as consisting of:

   (a) An Energy Conversion Package (ECP)
   (b) A Fluid Storage and Supply Package (FSSP)

   The interfaces between these packages is as defined in Figure 1.

   Although the TIR requested technical information on both the ECP and FSSP from the energy conversion unit manufacturers, in order to save time, it is not intended to procure the section in this manner. GAEC intends to integrate the energy conversion package with the cryogenic tank package and procure these items directly from their respective manufacturers.

2. A basic configuration for the Power Generation Section was conceived based on weight and reliability considerations. The recommended configuration is unstaged and consists of the following:

   (a) 3 - 50% fuel cell units
   (b) 1 - 100% oxygen tank
   (c) 1 - ascent sized o ygen tank
   (d) 1 - 100% hydrogen tank
   (e) 1 - ascent sized hydrogen tank
   (f) 2 - peaking batteries

   Several cryogenic tank configurations have been utilized for the purposes of comparing energy conversion devices.

   Pending the results of the forthcoming EPS-ECS integrated oxygen tank study, the tankage configuration selected may not represent the final tank arrangement.

   NOTE: * TAPCO subsequently withdrew from the study.

Definitions

Effective weight at LEM-CSM Separation = weight of item plus propulsion system weight required either to:

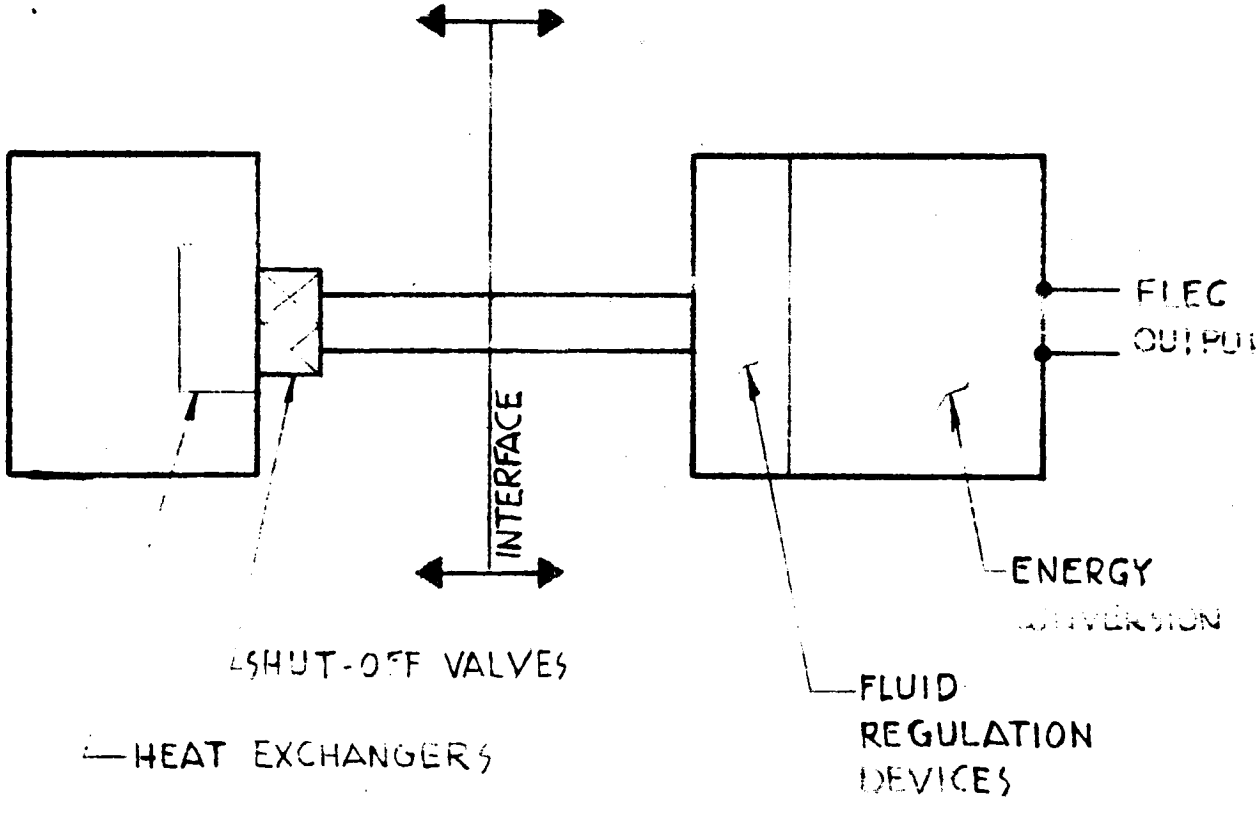
1. Place the item on the lunar surface

[redacted]

FIG. V-1 POWER GENERATION SECTION BLOCK DIAGRAM

FLUID STORAGE AND SUPPLY PACKAGE

ENERGY CONVERSION PACKAGE



Definitions - Continued

F100% Unit	Energy conversion unit to handle 100% of the maximum electrical load as defined by the load analysis.
F50% Unit	Energy conversion unit to handle 50% of the maximum electrical load as defined by the load analysis.
B50% Unit	Battery to handle 50% of maximum electrical load as defined by load analysis.
ECU	Energy conversion unit or module i.e., one fuel cell or one engine.
ECP	Combination of energy conversion units (ECU) and associated controls.
FSSP	Fluid Storage and Supply Package includes cryogenic tanks, controls, heat exhangers,----
PGS	Power Generation Section = ECP + FSSP.
Phase 1-11	Earth launch through LEM-CSM rendezvous, docking and crew transfer.
Phase 8-11	Pre-lunar launch checkout through docking and crew transfer.
Phase 1-8	Earth launch through pre-lunar launch checkout.
M100	Cryogenic tank sized for complete mission (Phases 1-11).
A100	Cryogenic tank sized for ascent phase of mission (Phases 8 - 11).
D100	Cryogenic tank sized for Phases 1 - 8.
A50	Cryogenic tank sized for 50% of the ascent phase of mission (Phases 8-11).
D50	Cryogenic tank sized for 50% of Phases 1 - 8.
EPS	Electrical Power Subsystem
ECS	Environmental Control Subsystem
PB	Peaking Batteries

Basic Study Criteria

The following study criteria was established at the start. In some cases, modifications were made and data and conclusions were altered as indicated.

1. The system would be subjected to a thirty hour pre-launch standby time in which no servicing of the system would be required (Reference 1).

Initially a 90 hour standby time was assumed and data was generated for this condition. This was later changed to 30 hours. Final weight data presented in this report is based on thirty hour standby time.

2. The LEM Power Generation Section will supply the electrical power required from earth launch to docking and crew transfer.

3. An abort or mission curtailment would be declared when one more failure would be catastrophic.

4. An emergency descent to lunar surface or ascent from lunar surface can be performed with one fifty percent energy conversion unit.

5. The Power Generation Section will be designed for day or night lunar mission.

6. The configuration study will be performed for Mission "A" and Mission "C"

Data Criteria

1. Tank Weights Data

Reactant storage system weight data was extracted from the four studies submitted (References 2, 3, 4, 5) and Gemini inputs and is plotted on one curve. This is shown in Figure 2. From this data, a composite curve of usable fluid vs. total filled system weight was arrived at. This is shown in Figure 3.

In all subsequent calculations the tank system weights derived from this curve were applied to all energy conversion units to determine the total PGS weight. This was done so as to negate the effect of the varying tank manufacturer's system weights on the selection of an Energy Conversion Unit configuration.

2. Expendable Cooling Water Requirements

The expendable cooling water requirements were broken down into that required for cooling the environmental control system exclusive of the EPS and that required for cooling the energy conversion unit.

The data is presented in Table 1.

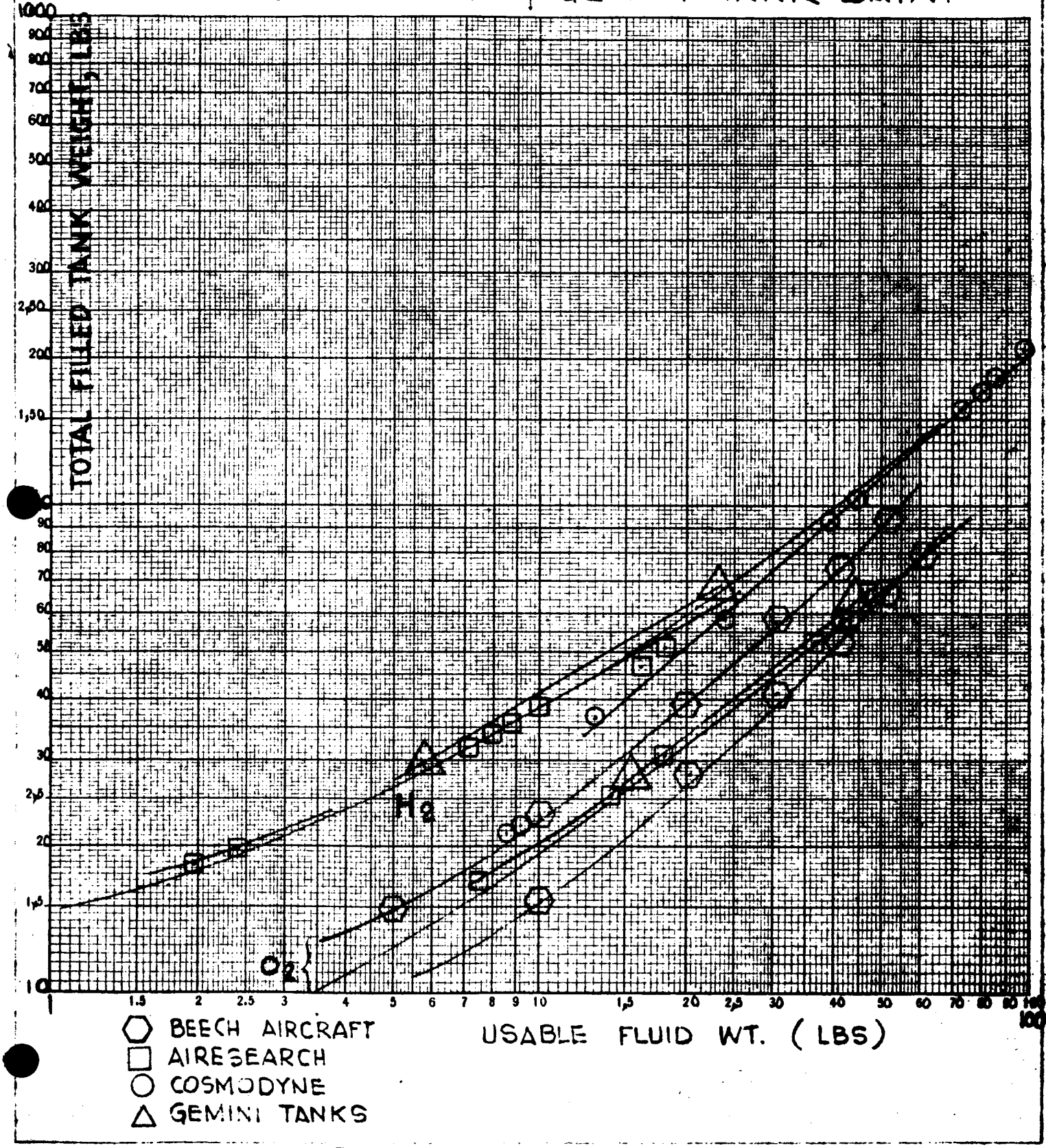
For the purpose of calculating the effective weight for system comparison, the data was summed and presented, as shown in Table 2, using the Sundstrand Cryho-cycle, which requires no water, as the zero base.

The water weights shown in Tables 1 and 2 have been adjusted for: systems which produce and reclaim water and for cooling produced by conversion of cryogenic fluids to the gaseous state.

3. Growth Factor

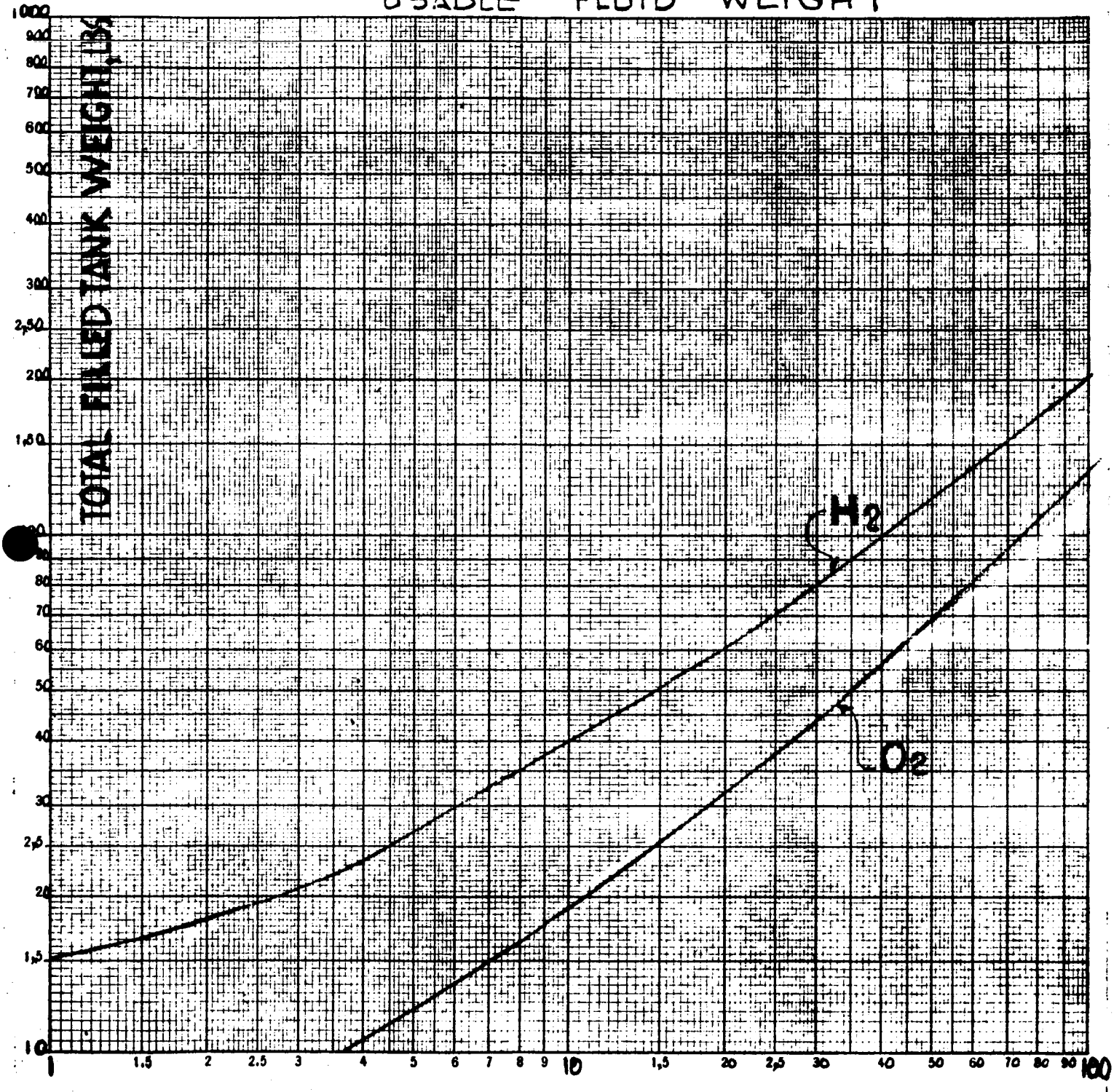
(a) The growth factor is the weight affect that each pound has on the total vehicle in terms of propellant, and a tankage increment to carry the additional propellant. This can be further expanded to include the additional propellant increment to carry the previous tankage increment and so forth.

FIG. V-2 : SUMMARY PLOT OF O_2 & H_2 TANKAGE WEIGHTS USING AIRESEARCH, BEECH, COSMODYNE & GEMINI TANK DATA.



[redacted]

FIG. V-3 : TOTAL FILLED TANK SYSTEM WEIGHT INCLUDING COMPONENTS VS. USABLE FLUID WEIGHT



(b) Growth Factor = $(1^{\#} + W_{p_1}) + W_{p_{t_1}} + W_{p_2} + W_{p_{t_2}}$

where: W_{p_1} = propellant required to carry the $1^{\#}$

$W_{p_{t_1}}$ = Tankage required to carry propellant W_{p_1}

W_{p_2} = propellant required to carry tankage increment $W_{p_{t_1}}$

(c) These values are established by using the ΔV's and specific impulses as follows:

	ΔV	Specific Impulse	Resultant G.F.
Descent	7740 fps	308 sec	2.4
Round Trip	(7740 + 6860 = 14620 fps)	311.5	5.1

NOTE: See Appendix A for the growth factor derivation.

4. Energy Conversion Unit Performance Data

References 2, 3, 4, and 5, responses to the GAEC TIR, presented performance and weight data on energy conversion units in various design and refinement stages.

The following units were used for the configuration study:

(a) General Electric - Gemini Cells and Gemini Performance

The performance presented represents actual test data on cells already built for the Gemini vehicle and which can be identically used in the LEM energy conversion unit.

(b) Pratt and Whitney - Apollo Design and Advance Performance

The performance presented represents estimated performance on 5 inch diameter electrodes to be designed similar to the Apollo structure and performance which has been obtained in test runs and is described as "Advanced Performance."

(c) Allis Chalmers - Present Performance

The performance and weights presented represents performance based on units already operating in the laboratory although not particularly designed for space flight application.

(d) Sundstrand Cryhocycle

The performance and weights presented are based on estimated and computed data and results obtained from experimental model engine test runs.

5. LEM Mission Considerations

Effective system weights including total cooling water requirements, peaking batteries, reactant and energy conversion packages were computed for Missions "A" and "C".

Configuration Study

The basic study was set up to consider three vehicle installations.

1. Unstaged Systems where the entire power generation section is carried in the ascent stage.

2. Staged Systems where the power generation section is comprised of two systems, one for supplying the electrical needs of the LEM from earth launch to lunar launch which is located in the descent stage of the LEM, and one which supplies the electrical needs of the LEM from lunar launch to docking located in the ascent stage of the LEM.

3. Staged Tankage included all the configurations in paragraph 1, with the reactant tankage split in the ascent and descent stages according to the power division.

The initial configurations considered are shown in Table 3.

This matrix was altered and reduced by qualitative methods to 27 final configuration of energy conversion units, batteries and tanks.

The evaluation of the three vehicle installations were performed in three major phases as described below:

(a) Unstaged Systems - Unstaged Tankage Systems vs. Staged Tankage Systems
(b) Staged Systems - Staged Fuel Cell Systems vs. Staged Battery Fuel Cell Systems
(c) Staged vs. Unstaged Systems

Systems were compared on the basis of effective weight at LEM-CSM separation and relative reliability.

Phase I - Unstaged Systems

The purpose of this investigation was to arrive at an optimum unstaged system configuration.

A series of all ECU and hybrid ECU battery combinations were selected for evaluation as follows:

(a) 2 - 100% ECU's (F100)
(b) 3 - 50% ECU's (F50)
(c) 3 - 100% ECU's (F100)
(d) 2 - 50% batteries B50 + 1 - 100% ECU's (F100)
(e) 1 - 50% battery B50 + 2 - 100% ECU's (F100)
(f) 2 - 50% batteries B50 + 2 - 100% ECU's (F100)

A tankage evaluation was performed to determine if any advantage could be obtained by staging tankage such that the tankage for the fluid consumed during translunar, descent and lunar stay, would be in the descent stage, and therefore left behind.

The configurations used for this phase are shown in Figures 4 and 5.

The systems were evaluated based on effective weight of equivalent configurations.

It was assumed that the staged tankage systems were less reliable than unstaged due to the addition of fluid and electrical disconnects, additional tanks etc.

The tabulated results of this study phase is shown in Table 4.

The results show that there is no significant effective weight advantage in staging tankage for P & W, G.E., and A.C. in both mission A and C considerations.

The Sundstrand Cryhocycle shows effective weight advantages of 118# (Mission A) to 170# (Mission C) in favor of the staged tankage configuration. Since the weight comparison did not take into account weight of lines, disconnects, electrical wiring and mounting considerations it was concluded that the weight advantage stated above was not significant.

A comparison was made of unstaged configurations including energy conversion units vs. hybrid battery - energy conversion units combustion. These are designated in Figure 4 as configuration 50, 60, 70 for ECU units and 80, 90 and 100 for the hybrid units. In all configurations energy conversion units considered alone were lighter by approximately 500 to 700# effective weight. This data comparison is shown in Table 5.

It is therefore concluded that configurations 50, 60 and 70 are the optimum unstaged configurations.

Phase 2 - Staged System

The purpose of this investigation was to arrive at an optimum staged configuration.

Four basic configurations were conceived for the ascent stage and four basic configurations conceived for the descent stage. These are summarized in Table 6. The total number of configurations considered were 15. System 4 - 1 was judged illogical and eliminated immediately. It should be noted that the system 1 to 4 are listed in the order of descending reliability. A matrix of system designations was arrived at and is shown in Table 7.

TABLE 7

DESIGNATION OF STAGED SYSTEMS

1 - 1	2 - 1	3 - 1	4 - 1
1 - 2	2 - 2	3 - 2	4 - 2
1 - 3	2 - 3	3 - 3	4 - 3
1 - 4	2 - 4	3 - 4	4 - 4

Represents Decreasing Reliability in Descent Stage

Represent Decreasing Reliability in Ascent Stage

The fifteen configurations were evaluated first on effective weight and then relative reliability. Table 8 and 9 presents a tabulation of effective weights of the 15 configurations for the four manufacturers based on Missions C and A requirements respectively. It should be noted that Sundstrand did not propose Cryhocycle variations for all configurations.

All staged battery configurations, including 1-1, 1-2, 1-3, and 1-4 for all manufacturers are seen to be at least 300# effective weight heavier than staged fuel cell configurations.

Therefore all staged battery configurations were eliminated from further consideration.

Configurations 2-1 and 3-1 were eliminated for all manufacturers relative to configurations 2-2 and 3-2 based on being at least 250# effective weight heavier and having equal reliability.

Configurations 2-3, 3-3, 4-3 were eliminated as being generally heavier than 2-2, 3-2, 4-2 and of lesser reliability.

The remaining configurations 2-2, 3-2, 4-2, 2-4, 3-4, 4-4 were selected for final comparison with the unstaged configurations.

Phase 3 - Staged vs. Unstaged Systems

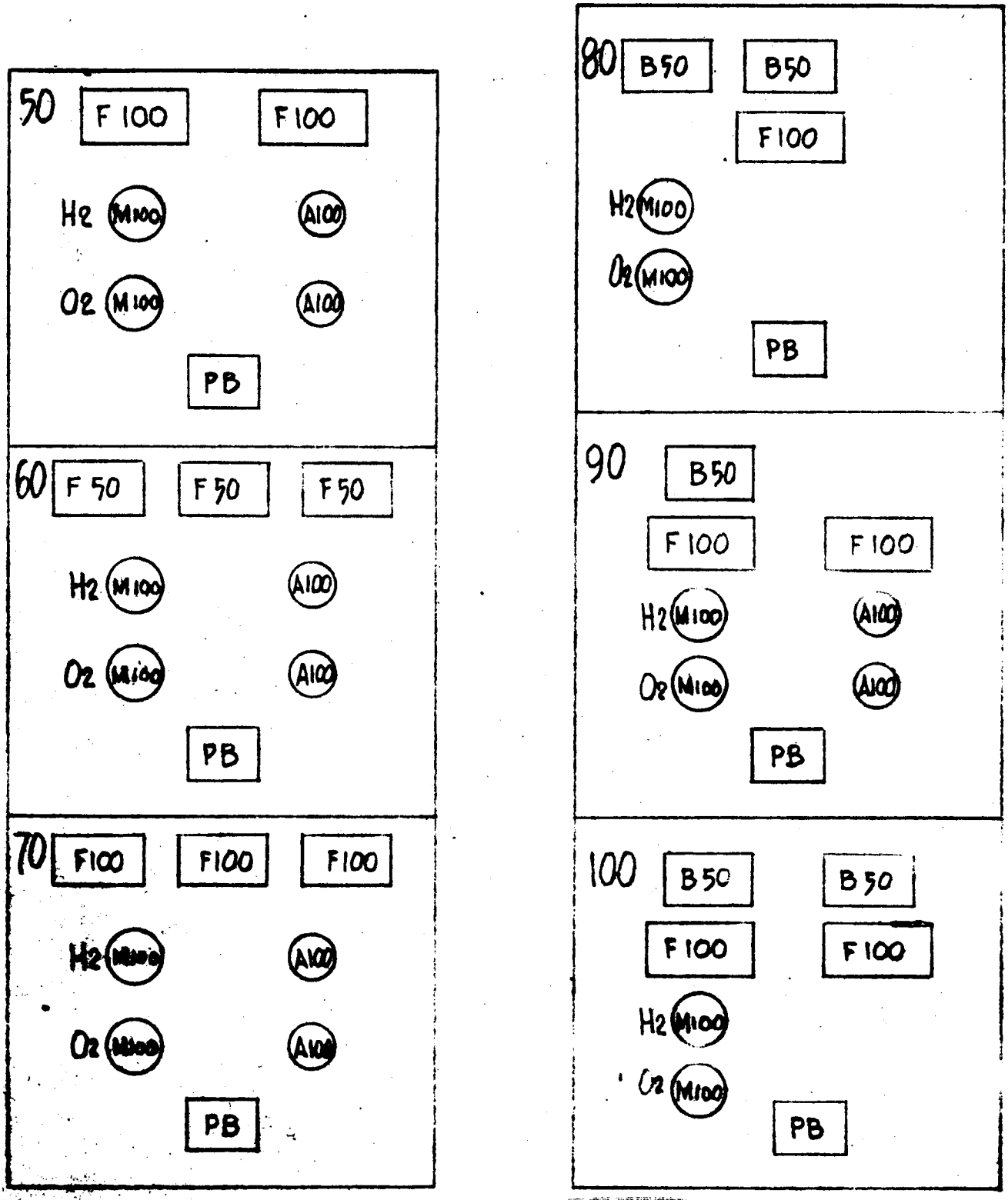
The remaining staged and unstaged systems were compared on a weight and reliability basis as shown in Table 10.

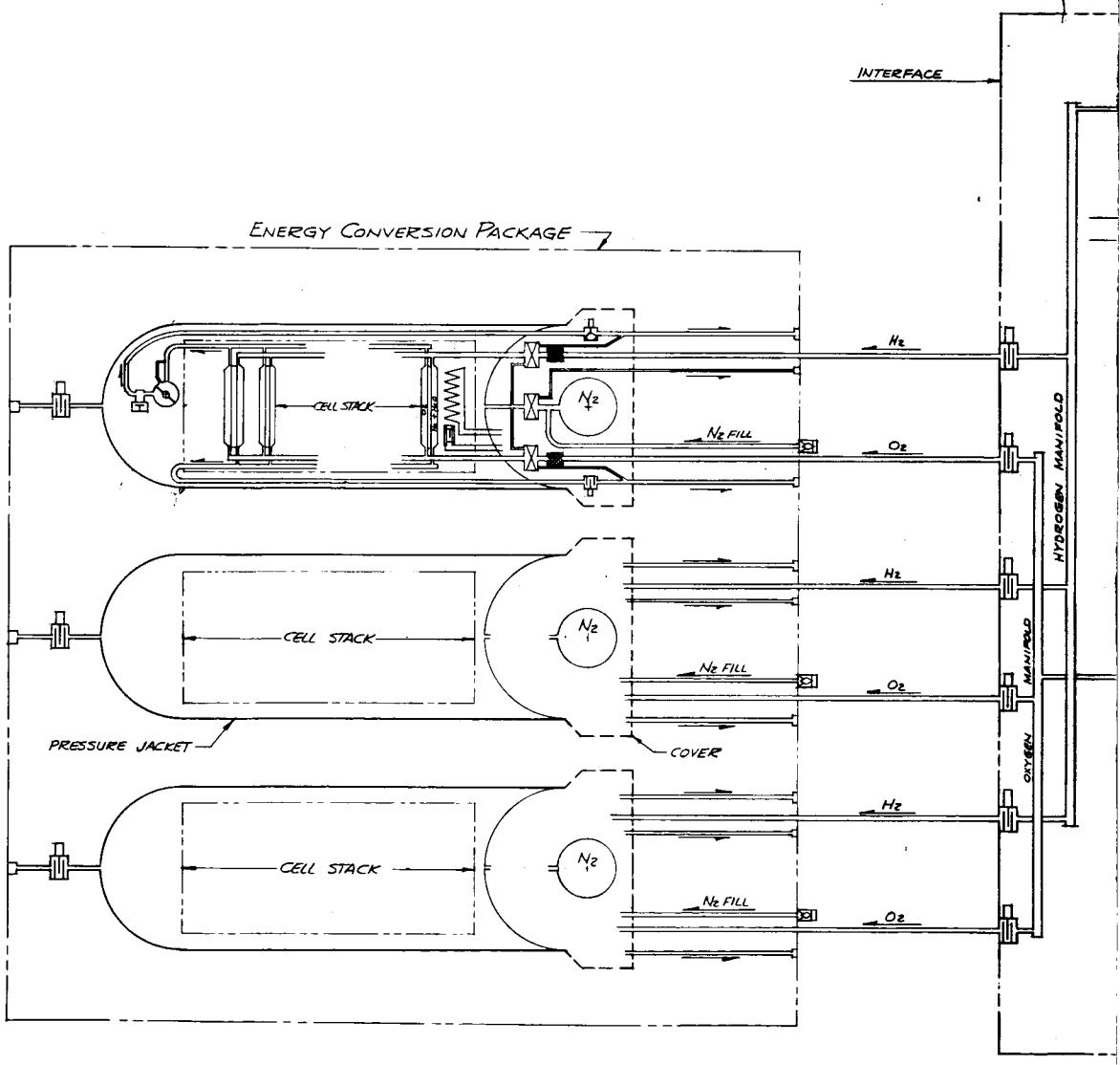
Conclusions

1. Configuration 60 and 70 presented the highest relative reliability for both crew safety and mission completion reliabilities.

2. Configuration 60 presented the lowest weight of all staged and unstaged configurations except for configurations 42 and 44 and P & WA configurations 50, and G.E. configuration 50, mission A.

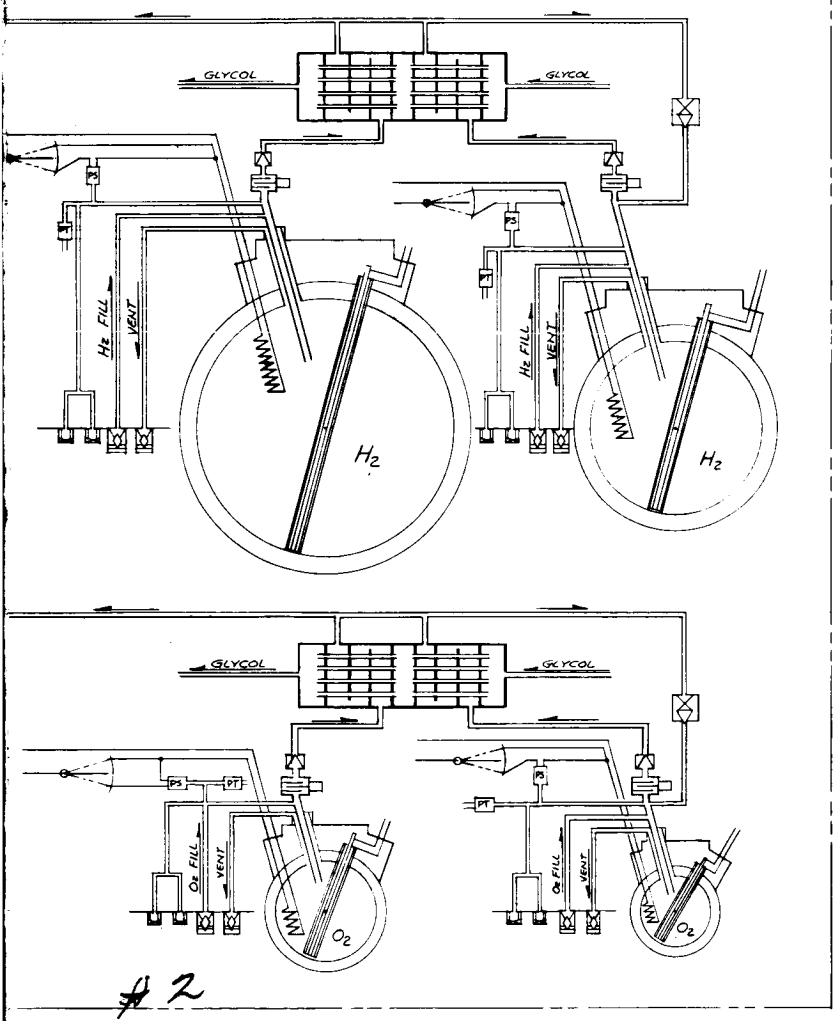
FIG. V-4 UN-STAGED CONFIGURATIONS




INTERFACE
ENERGY CONVERSION PACKAGE
CELL STACK
N_2
N_2 FILL
H_2
O_2
CELL STACK
N_2
N_2 FILL
H_2
O_2
PRESSURE JACKET
COVER
CELL STACK
N_2
N_2 FILL
H_2
O_2
HYDROGEN MANIFOLD
OXYGEN MANIFOLD

#1

FLUID STORAGE AND SUPPLY PACKAGE



#2

NAME	SYMBOL
ELECTRIC SWITCH	
TEMPERATURE SENSOR (DRY)	T
TEMPERATURE SENSOR (FLUID)	T
PRESSURE TRANSDUCER	PT
PRESSURE SWITCH	PS
RELIEF VALVE	
QUICK DISCONNECT VALVE (WITH CAP)	
FLOW CONTROL VALVE	
THREE POSITION VALVE (ELECTRIC)	
SOLENOID VALVE (ON-OFF)	
THERMAL PRESSURE RELIEF VALVE	
CHECK VALVE	DIRECTION OF FLOW
CRYOGENIC STORAGE TANK	
HEAT EXCHANGER (FLUID TO FLUID)	
FLUID QUANTITY SENSOR	
FILTER	
PRESSURE REGULATOR	
ELECTRIC HEATING ELEMENT	
INERT GAS TANK	N_2
SINGLE CELL	
FUEL CELL	

LEGEND

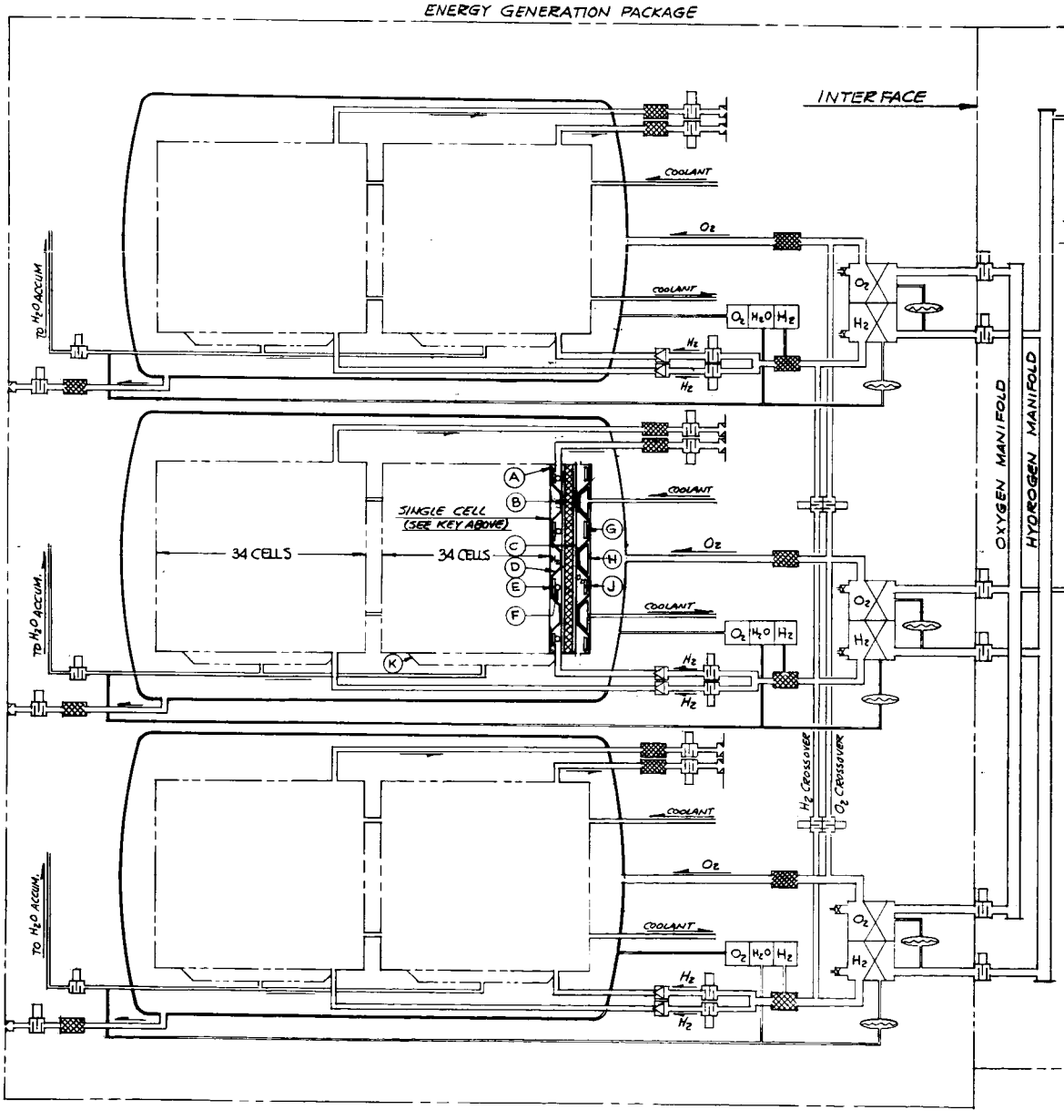
	4
	1 PER FUEL CELL
	1 PER FUEL CELL
	4
	4
ON ER /	8
	11
	1 PER FUEL CELL
	1 PER FUEL CELL
	16
ION DW	2
	4
	4
	2
	4
	2 PER FUEL CELL
	3 PER FUEL CELL
	1/CRY TANK /FUEL CELL
	PER FUEL CELL
	3
	N° USED

#3

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCE UNLESS SPECIFIED FRACTIONS - DECIMALS - ANGLES	DRAWN BY	H. G. BIENN	GRUMMAN AIRCRAFT ENGRG CORP BETHPAGE, L. I., N. Y.
	LAYOUT BY		
	CHECKED BY	H S SIEGEL 12-6-63	POWER GENERATION SECTION
NONE	GR LEADER	HSS	PRATT & WHITNEY ECP & FS & SP
ORIG DWG AUTH	STRUCTURE		CONTRACT NO
DETAIL SPEC REQUIREMENT	STRUCTURE		CODE IDENT NO 26512 / SIZE F / LSK-390-10002
CLASS II ENGRG CHANGE	WEIGHTS		
CLASS I ENGRG CHANGE	PROJ ENGR		
GRUMMAN REL INFO	GOVT APPD		SCALE NONE / FIGURE IV-6 / SHEET 1 OF 1

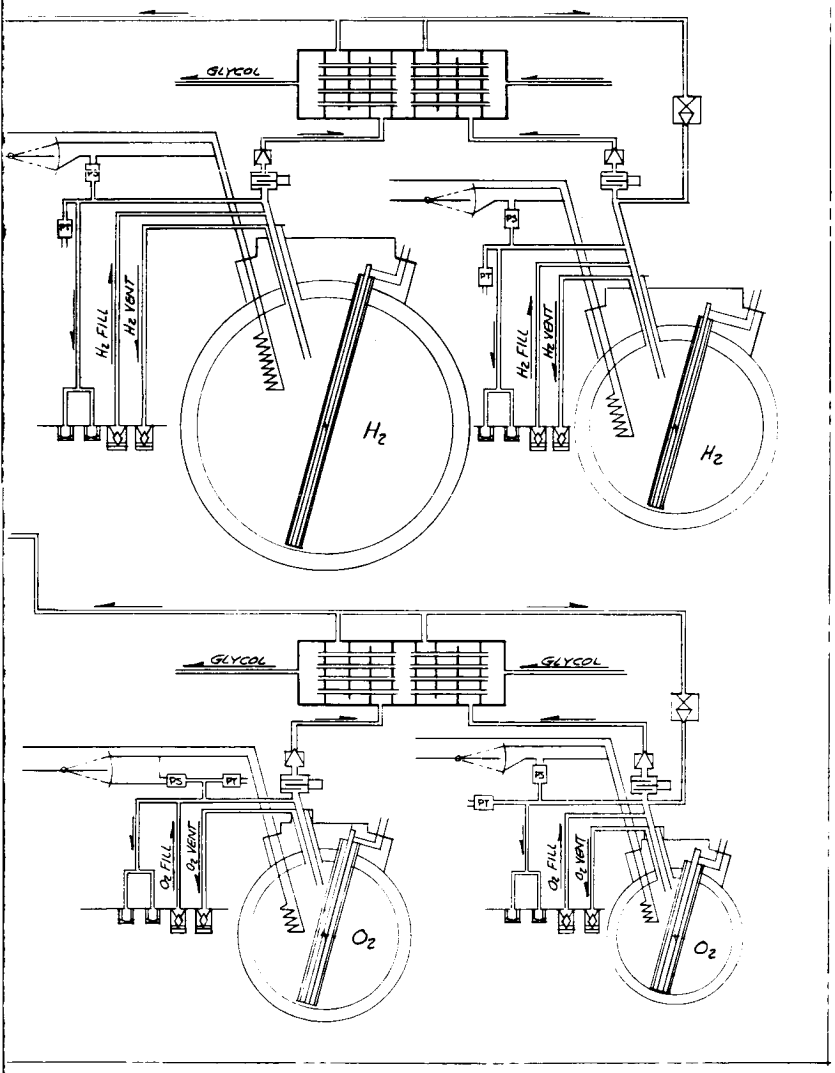
LET.	NAME	NOTES
K	PRODUCT WATER SUMP	
J	O_2 CURRENT COLLECTOR	ROTATED 90°
H	COOLANT TUBE	FOR THIS
G	H_2O WICKS	DIAGRAM
F	RECYCLE WICKS	
E	H_2 SIDE WICKS	
D	H_2 CURRENT COLLECTOR	
C	CATALYTIC ELECTRODE	
B	SOLID ELECTROLYTE	
A	FRAME	

FUEL CELL KEY



#1

FLUID STORAGE AND SUPPLY PACKAGE



NAME	SYMBOL
LEGEND	
MODUEL	
SINGLE CELL	SEE DIAGRAM AND KEY
PRESSURE SENSOR	O2 H2O H2
ELECTRIC HEATING ELEMENT	
RESTRICTOR	
FILTER	
FLUID QUANTITY SENSOR	
HEAT EXCHANGER (FLUID TO FLUID)	
CRYOGENIC STORAGE TANK	
CHECK VALVE	DIRECT OF FLOW
OXYGEN-HYDROGEN FLOW REGULATOR	O2 H2 TO PROCESS WATER
QUICK DISCONNECT VALVE (WITH CAP)	
SOLENOID VALVE (ON-OFF)	
RELIEF VALVE	
PRESSURE SWITCH	PS
PRESSURE TRANSDUCER	PT
ELECTRIC SWITCH	

#2

4	
4	
4	
14	
8	
32	
3	
10	
4	
2	
4	
15	
9	
4	
3	
34 PER STACK	
3	
NO USED	

#3

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCE UNLESS SPECIFIED FRACTIONS - DECIMALS - ANGLES NONE	DRAWN BY	H. G. BIRNN	GRUMMAN AIRCRAFT ENGRG CORP BETHPAGE, L. I., N. Y.
	LAYOUT BY		
	CHECKED BY	W.S. SCHAEFER 4-24-63	POWER GENERATION SECT.
	GR LEADER	E.S.S.	GENERAL ELECTRIC E.C.P. & F.S.& S.P.
ORIG DWG AUTH	STRUCTURE		CONTRACT NO
DETAIL SPEC REQUIREMENT	STRUCTURE		CODE IDENT NO 26512 / SIZE F / LSK-390-10001
CLASS II ENGRG CHANGE	WEIGHTS		
CLASS I ENGRG CHANGE	PROJ ENGR		
GRUMMAN REL INFO	GOVT APPD		SCALE NONE / FIGURE V-7 / SHEET 1 OF 1

FIG. V-5

STAGED TANKED CONFIGURATIONS

55

B50 B50

F100

H_2 (A) 100 O_2 (A) 100

PB

H_2 (D) 100 O_2 (D) 100

85

F100 F100

H_2 (A) 100 H_2 (A) 100

O_2 (A) 100 O_2 (A) 100

PB

H_2 (D) 100 O_2 (D) 100

65

B50

F100 F100

H_2 (A) 100 H_2 (A) 100

O_2 (A) 100 O_2 (A) 100

PB

H_2 (D) 100 O_2 (D) 100

95

F50 F50 F50

H_2 (A) 100 H_2 (A) 100

O_2 (A) 100 O_2 (A) 100

PB

H_2 (D) 100 O_2 (D) 100

75

B50 B50

F100 F100

H_2 (A) 100 O_2 (A) 100

PB

H_2 (D) 100 O_2 (D) 100

105

F100 F100 F100

H_2 (A) 100 H_2 (A) 100

O_2 (A) 100 O_2 (A) 100

PB

H_2 (D) 100 O_2 (D) 100

3. It is therefore concluded that for mission C requirements configuration 60 is the optimum configuration based on weight and reliability considerations.

Study Data Summary

Tables 11, 12, and 13 summarize the major design characteristics i.e., weight, volume...of the selected configuration for GE, P & WA and Sundstrand, respectively.

Tables 14, 15, and 16 contain in more detail the GE data utilized in comparing system weights and volumes. Similarly, Tables 17 and 18 contain P & WA data, Tables 19 and 20 illustrate Allis-Chalmers performance capabilities and Table 21 summarizes the Cryhocycle system characteristics.

Power generating sections utilizing the Pratt and Whitney and General Electric fuel cells are shown schematically in figures 6 and 7, respectively. These schematics represent the selected configuration.

Appendix B illustrates the calculation of effective system weights using the growth factors described in Appendix A in conjunction with the data submitted by the companies participating in the study.

Appendix C contains the original data sheets (in reduced size) that were used in performing the system weight trade-offs.

Appendix D is a thermodynamic evaluation of the energy conversion concepts proposed to GAEC.

Appendices E and F briefly review the tankage system philosophy utilized in this study and the effect of trans-lunar energy requirements on the LEM EPS.

References

1. Grumman Aircraft Engineering Corporation.
   Technical Information Request and Description of Power Generation Section for the LEM Electrical Power Subsystem.
   Date: 28 January 1963

2. Sundstrand Aviation.
   A Technical Study Concerning the Application of the Cryhocycle Power Generation and Thermal Control System to the Lunar Excursion Module (LEM).
   Date: 11 February 1963
   Volume I Introduction and Summary
   Volume II Technical Discussion
   Volume III Appendices

3. Pratt and Whitney Aircraft.
   Description of Power Generation Section for LEM Electrical Power Subsystem.
   Date: 13 February 1963.

4. General Electric.
   Fuel Battery Power Generation Section Technical Configuration Study for Lunar Excursion Module.
   Date: February, 1963

References - Continued

5. Allis-Chalmers Manufacturing Co.
Technical Information for the Power Generation Section of the LEM Electrical Power Subsystem.
Date: 11 February 1963

APPENDIX "A" - GROWTH FACTOR DERIVATION

1) $V = gI_s \ln W_o/W_f$ where I_s = Spec. Impulse, W_o = Initial W_t
W_f = Final or inert wt.

2) IF $V/gI_s = K$

3) Then $e^k = W_o/W_f$ = Mass Ratio

-For Descent

V's = 410 + 6560 + 770 = 7740 fps.

K = 7740.32.2 x 308 = 7740/9918 = .780

Then Mass Ratio = 2.182

Check: $W_p = W_o - W_f$

from 3) above $W_o = W_f e^k$

$W_p = W_f e^k - W_f$

$W_p = W_f (e^k - 1)$

W_p = 1# (2.182.1) = 1.182 = Propellant Penalty (W_{pl})

Thus verification of Mass Ratio =

1# Added
+1.182 W_{pl}
2.182 = Mass Ratio

W_{ptl} + .095 = Tank Increment to Carry (@.08 # of sys/# of prop.)

W_{p2} + .112 = Propellant for Tank Increment

W_{pt2} + .009 = Tank Increment for Propellant Increment W_{p2}

Desc. Growth Factor 2.398 Used 2.4

For Ascent to Circulat Orbit

$$K = \frac{6660}{32.2 \times 311.5} = \frac{6660}{10030} = .6640 = 1.943 = \text{Mass Ratio}$$

For Rendezvous Phase

$$K = \frac{220}{32.2 \times 260} = \frac{220}{8372} = .0263 = 1.021 = \text{Mass Ratio}$$

Total Ascent Mass Ratio = 1.943 x 1.021 = 1.984

Appendix "A", Continued.

Where W_p = 1# (1.984-1) = .984 = W_{pl}

Then	1#	Added
	+ .984	= W_{pl}
	1.984	= Mass Ratio
W_{ptl}	.069	= Tankage Increment to Carry Propellant (.07# of Sys/# of Propell.)
W_{p2}	.068	= Propellant to Carry Tankage Increment
W_{pt2}	.005	

Ascent Growth Factor 2.126 USE 2.13

Growth Factor for Round Trip = 2.4 x 2.13 - 5.11
Use 5.1

CONCLUSION

A. Comparison of Growth Factor and Mass Ratio

	Growth Factor	Mass Ratio
Descent	2.4	2.18
Ascent	2.13	1.98
Round Trip (Product of Above)	5.1	4.3

In comparing the Growth Factor vs. the Mass Ratio, the following facts are pertinent:

1. The value for the round trip is the product of the descent and ascent values.

2. They are both derived using the appropriate Vs and specific impulses during the various mission phases.

3. The Growth Factor is different from the Mass Ratio in that it accounts for the additional increments of propulsion system weight required per pound of propellant added and, further the additional propellant required to carry the tankage increment, etc. The expression is as follows:

$$G.F. = (1 + W_{pl}) + W_{tl} + W_{p2} + W_{t2} \cdots\cdots$$

Appendix "A", Continued

Where $(1 + W_{pl})$ = Mass Ratio

W_{t1} = # of Propulsion Sys/# of Propellant Added

W_{p2} = # of Propell. required to carry W_{t1}

W_{t2} = # of Propul. Sys. required to accommodate W_{p2}

B. Application of Growth Factor in various studies

1. Descent - All items carrier down to lunar surface should be multiplied by G.F. = 2.4

2. Round Trip - All non-variable items carried from separation to final docking should be multiplied by G.F. - 5.1

It should be noted that items which are consumed on the lunar surface (Water, H_2, O_2) must be separated so that the 5.1 growth factor is not inadvertently applied to these consumables.

(a) Round Trip using Ascent and Descent Growth Factors - If it is desirable to illustrate the round trip by showing the descent G.F. (2.4) and the ascent G.F. (2.13) from lunar lift-off to final docking, it is important to remember that their product = 5.1.

Example: A 5# item is carried down and up

1. 5# x 2.4 = 12# Descent Effective Weight
   x 2.13 Ascent G.F.
   25.5 Total Effective Weight - Round Trip

2. Check 5# x 5.1 = 25.5#

(b) Round Trip using Factors as a Cumulative Total rather than Products - In a tabular format, where it is convenient to show the vehicle weight at separation and at lunar lift-off, it is sometimes an advantage to use the round trip growth factor (5.1) as follows:

Example: A 5# item is carried down and up

1. Descent = 5# x 2.4 = 12# effective weight
   Ascent = 5# x 2.7 = 13.5 effective weight
   25.5# Total effective weight - Round Trip

2. Check 5# x 5.1 = 25.5#

3. The methods outlined in 2.(a) and (b) above, used properly, give the same effective weight for the round trip.

Appendix VB SAMPLE CALCULATIONS

Calculation of System Weights and Effective Weights

Unstaged Configuration GE #50

	1 Weight at Earth Launch	2 Weight at Separation	3 Effective Weight of 2	4 Weight at Lunar Launch	5 Effective Weight of 4	6 Sum of 3 & 5
ECS	393	321		120		
F100 F100	155	155		155		
H_2 M100	32	30.5		27.6		
H_2 A100	19.4	19.4		19.4		
O_2 M100	70	68.3		35		
O_2 A100	32.5	32.5		32.5		
	20	20		20		
TOTAL	721.9	646.7	1552	409.5	1100	2652

Staged Configuration GE #55

	1 Weight at Earth Launch	2 Weight at Separation	3 Effective Weight of 2	4 Weight at Lunar Launch	5 Effective Weight of 4	6 Sum of 3 & 5
ECS	393	321		120		
F100 F100	155	155		155		
H_2 A100 A100	38.8	38.8		38.8		
O_2 A100 A100	65	65		65		
PB	20	20		20		
H_2 D100	24.5	23				
O_2 D100	50	38.3				
TOTAL	746.3	661.1	1587	398.8	1077	2664

Appendix C -

STUDY DATA SHEETS

RELIABILITY

CREW SAFETY | MISSION CONFIG.

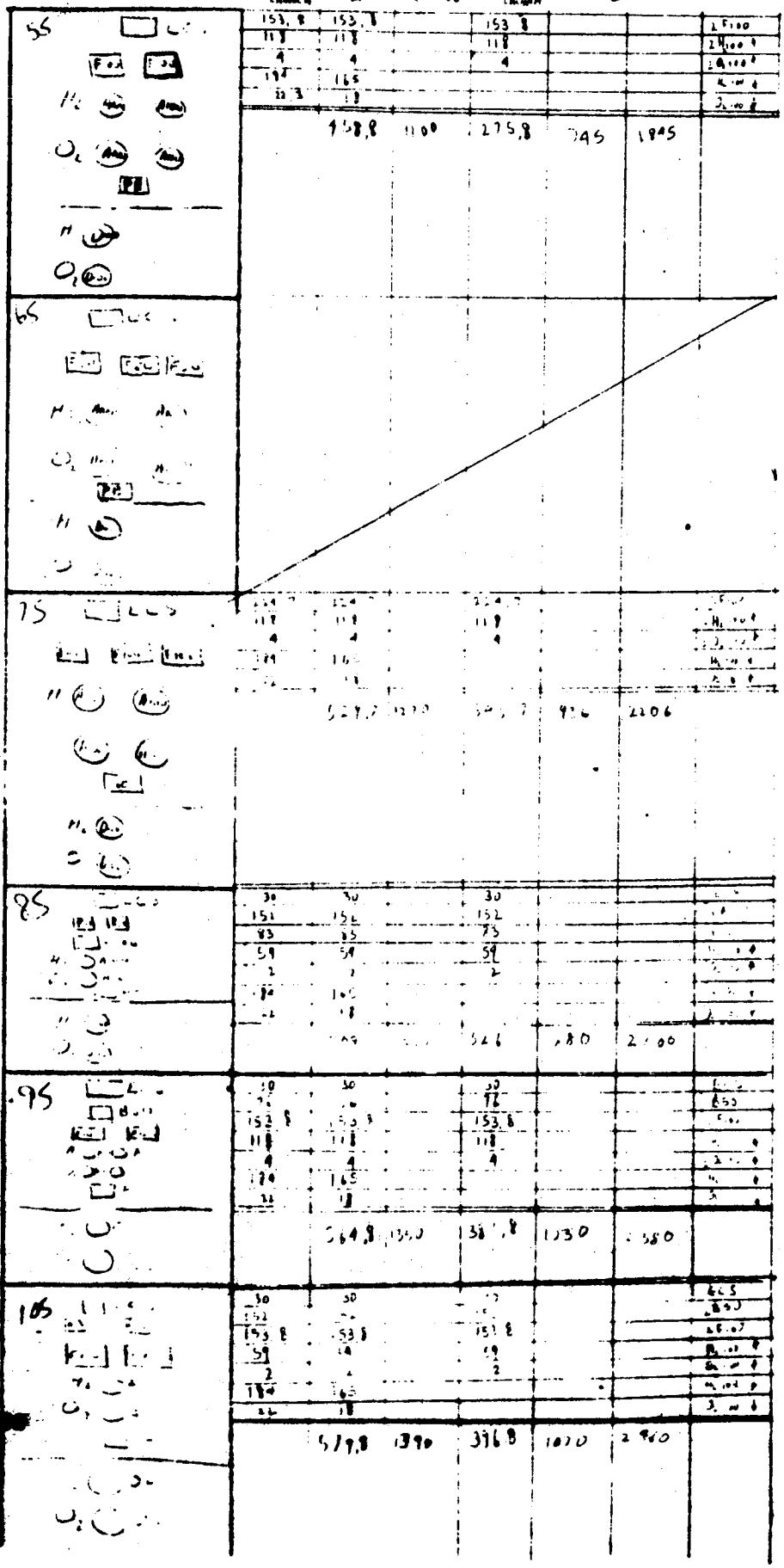
STAGED TANKAGE

SUND A

①	②	2A	③	3A	④	SUND
W LAUNCH	W	W	W LAUNCH	W	[2A-3A]	A

SUND.

A



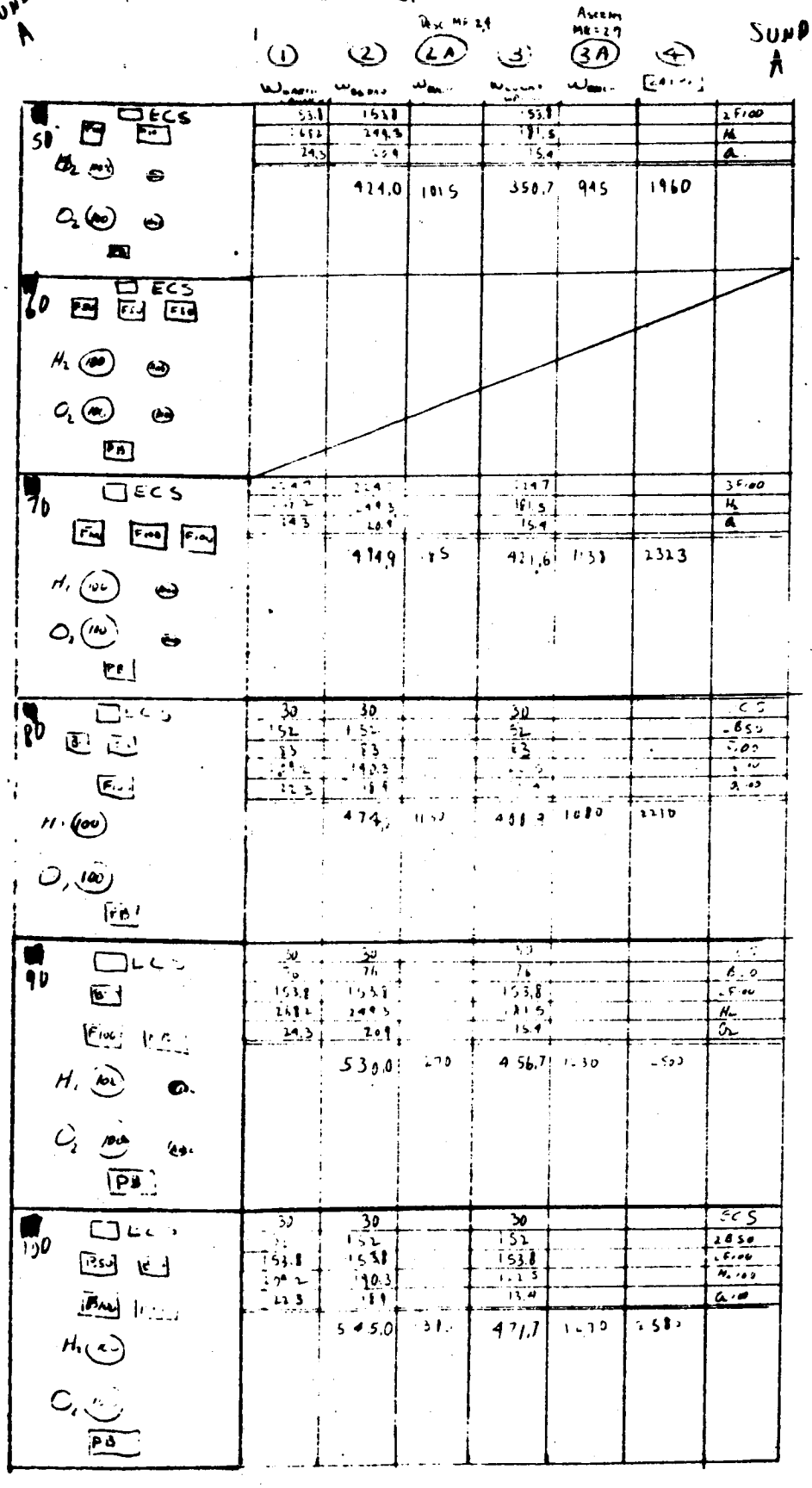
UN STAGED

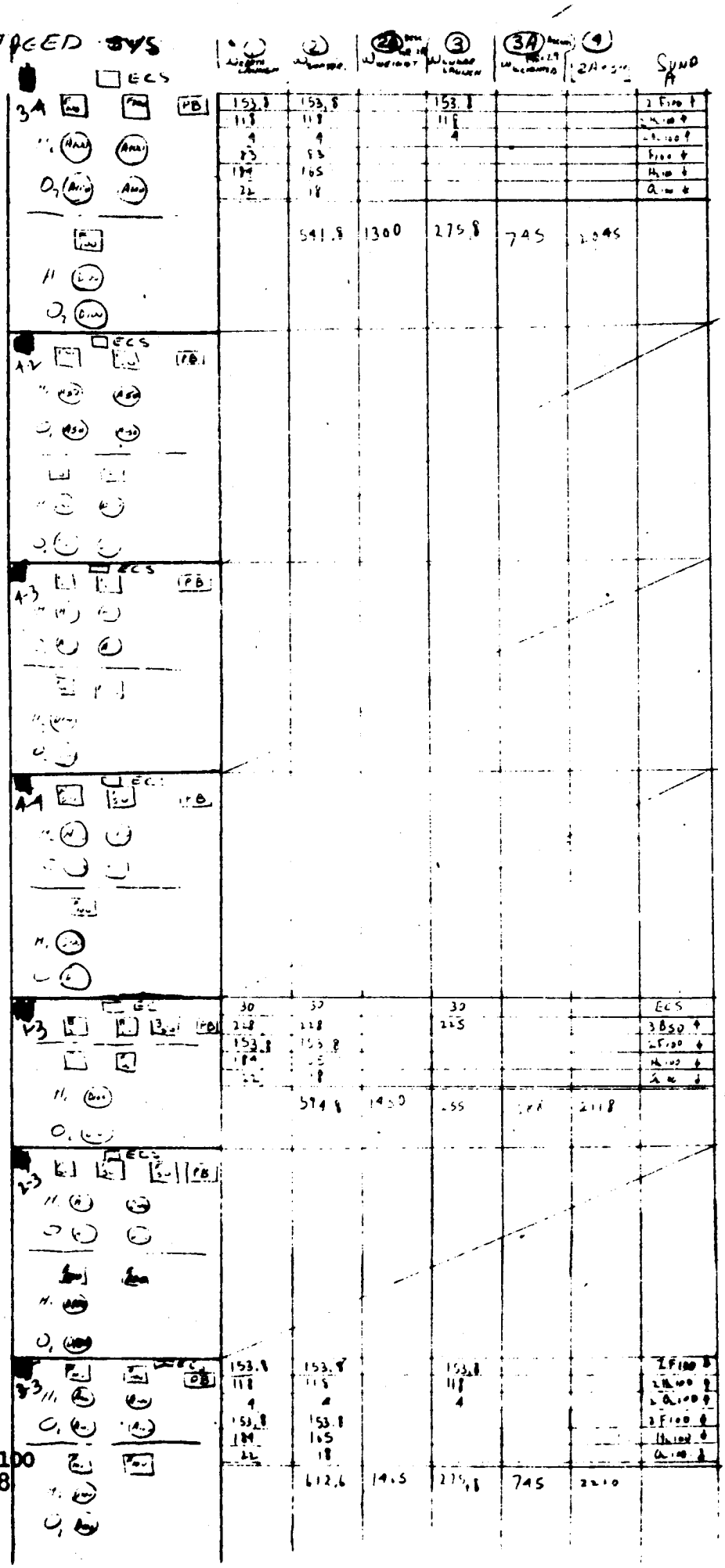
SUND A

SUND A

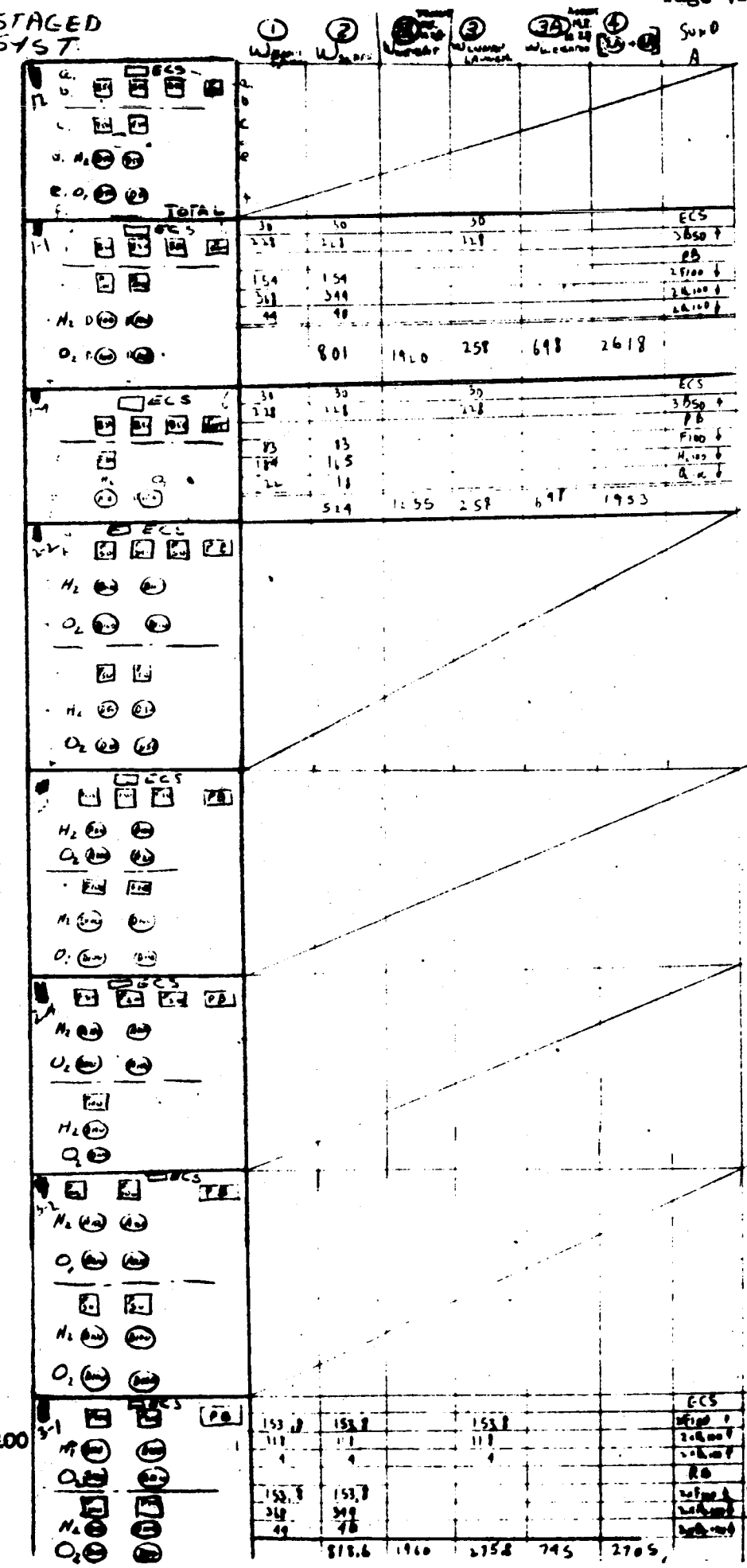
SUND.

A




SPACED SYS
ECS
SUND A
SUND
A

STAGED SYST.


SUND
A
ECS
Total
801
1910
258
698
2618
514
1155
258
697
1953
818.6
1960
2758
745
2705

STAGED TANKAGE

	①	②	2A	③	3A	④	SUMD C
55 ECS	139	159		159			25.00
FSU FSU	209	209		209			18.00 ↑
H_2	5	5		5			16.00 ↑
O_2	159	140					8.00 ↓
PB	21	17					8.00 ↓
H_2	543	520	1250	383	990	2230	
O_2							
65 ECS							
FSU FSU FSU							
H_2							
O_2							
PB							
H_2							
O_2							
75 ECS	159	225		225			35.00
FSU FSU FSU	209	209		209			18.00 ↑
H_2	5	5		5			16.00 ↑
O_2	159	140					8.00 ↓
E	21	17					8.00 ↓
H_2	614	591	1410	434	1170	2580	
O_2							
85 ECS	84	84		84			ECS
FSU FSU	266	266		266			850
FSU	83	83		83			25.00
H_2	102	102		102			18.00 ↑
O_2	3	3		3			16.00 ↑
PB	159	140					8.00 ↓
H_2	21	17					8.00 ↓
O_2	718	695	1660	538	1450	3110	
95 ECS	84	84		84			ECS
850	133	133		133			850
FSU FSU	159	159		159			25.00
H_2	209	209		209			18.00 ↑
O_2	5	5		5			16.00 ↑
PB	159	140					8.00 ↓
H_2	21	17					8.00 ↓
O_2	760	737	1770	580	1560	3330	
105 ECS	84	84		84			ECS
850	266	266		266			850
FSU FSU	154	154		154			25.00
H_2	102	102		102			18.00 ↑
O_2	3	3		3			16.00 ↑
PB	159	140					8.00 ↓
H_2	21	17					8.00 ↓
O_2	789	766	1830	609	1690	3470	

SUMD C

UN STAGED

SUND C

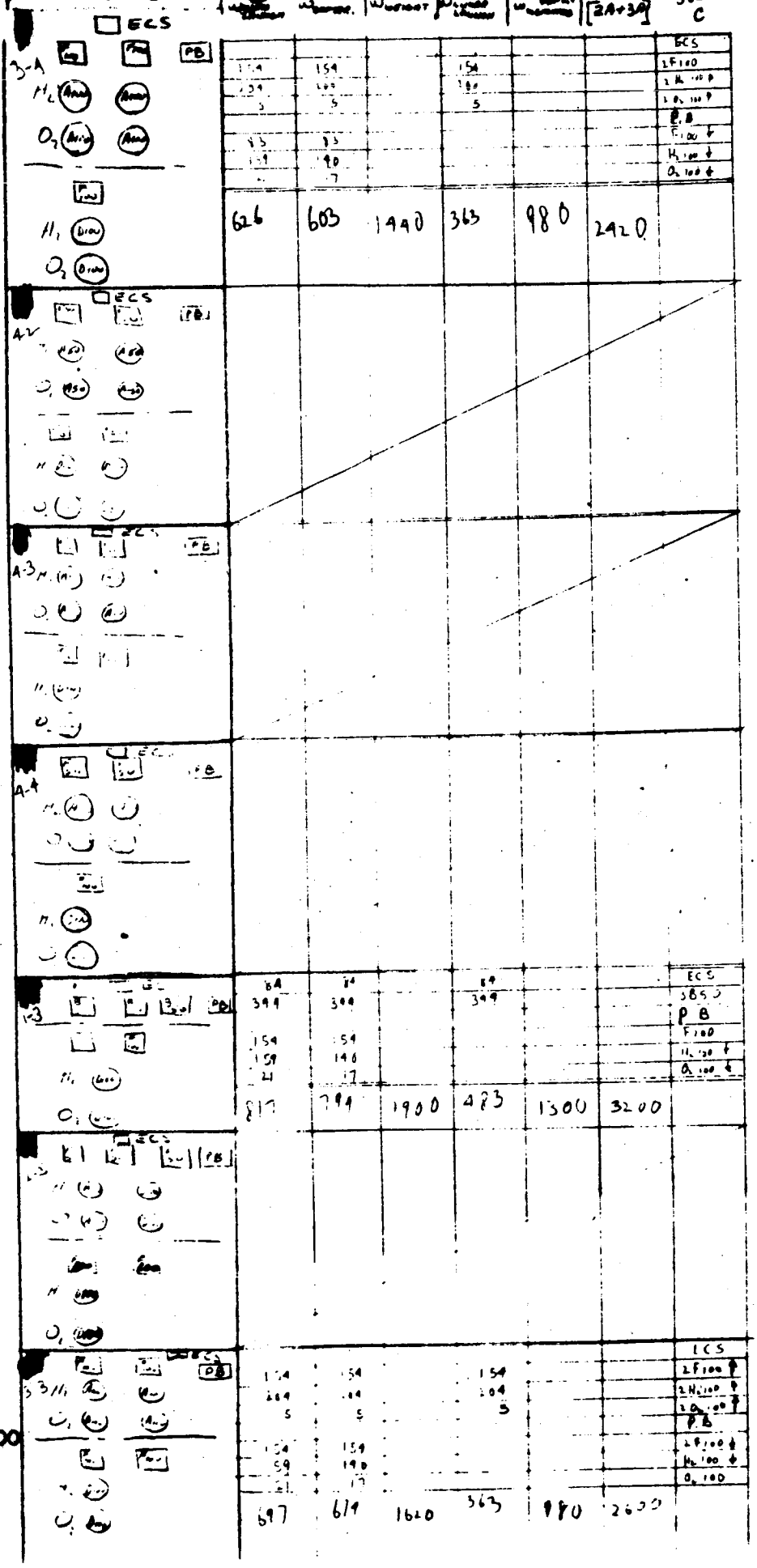
	(1)	(2)	(2A)	(3)	(3A)	(4)	SUND C
50 ECS	154	154		154			
	526	503	1210	441	1190	2400	
60 ECS							
70 ECS	597	574	1510	512	1380	2750	
80	700	677	1620	615	1665	2780	
90	743	720	1720	658	1770	2849	
100	771	748		686			

RECOVERY CREW MISSION SAFETY GROUP

SUND. "C"

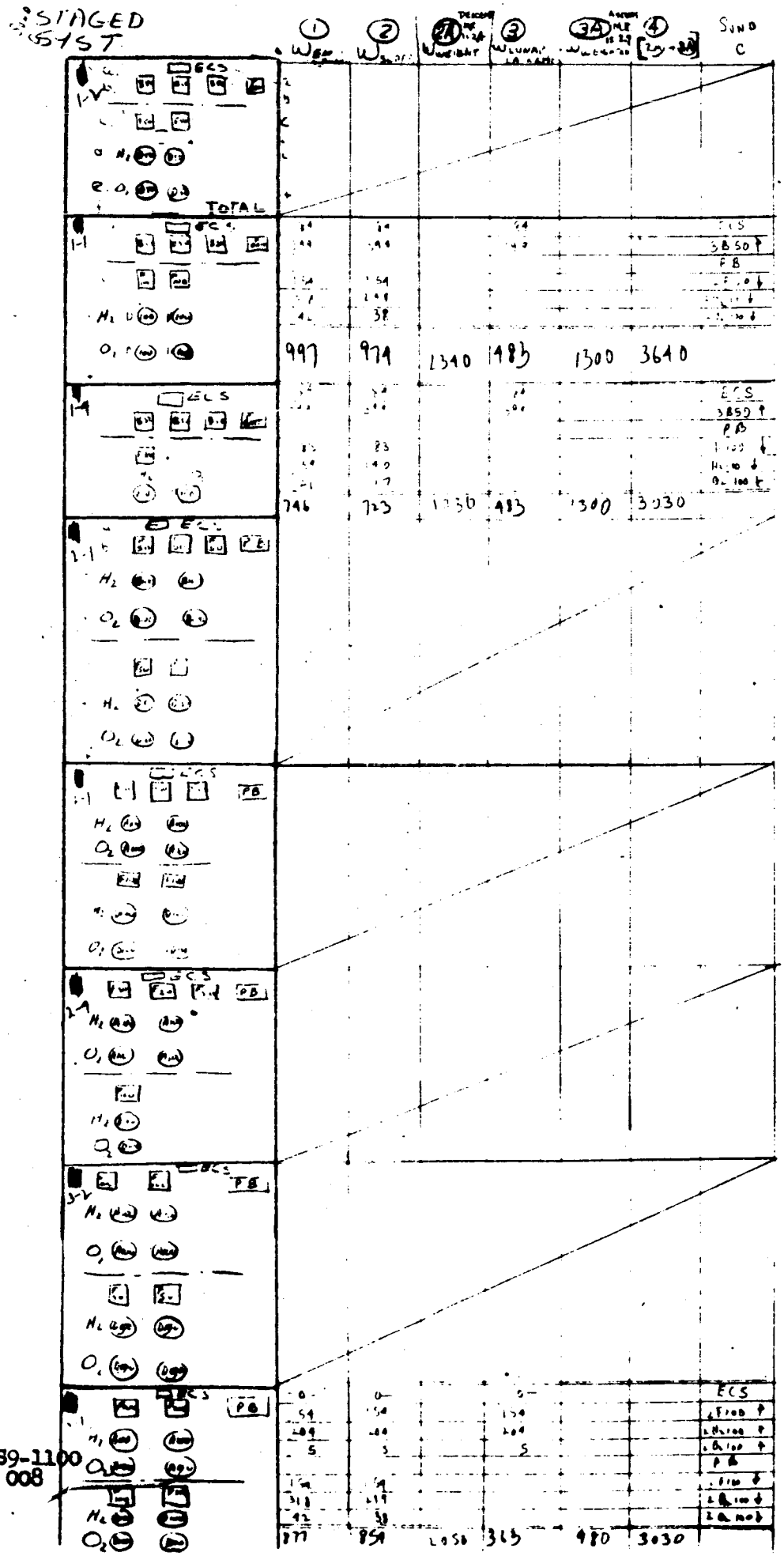
STAGED

SUND.
"C"



SUND.

MISSION "C"



STAGED TANKAGE

P&W A

	① W Launch Loaded	② W SEP	2A W Recontact Mission	③ W Landing Loaded	3A W Abort Propellant [2A+3A]	④	P&W A
55	665.3	603.1	1450	319.3	860	2310	
65	693.6	630.3	1510	346.6	930	2440	
75	765.4	703.2	1680	419.4	1130	2810	
85	681.1	618.9	1480	335.1	900	2380	
95	741.3	679.1	1620	395.3	1060	2680	
105	781.3	719.1	1720	435.3	1170	2890	

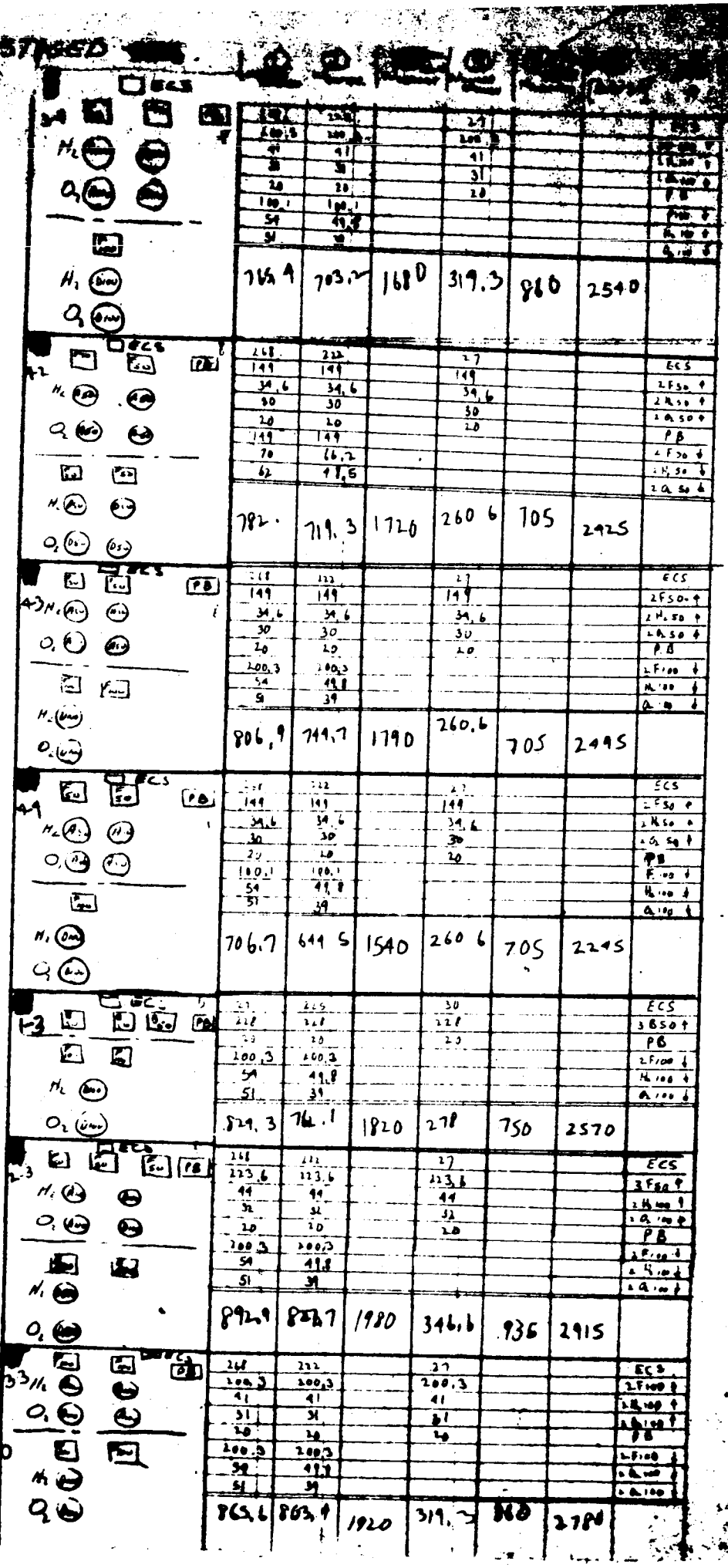
P&W A

UNSTAGED

P&W A

P&W A

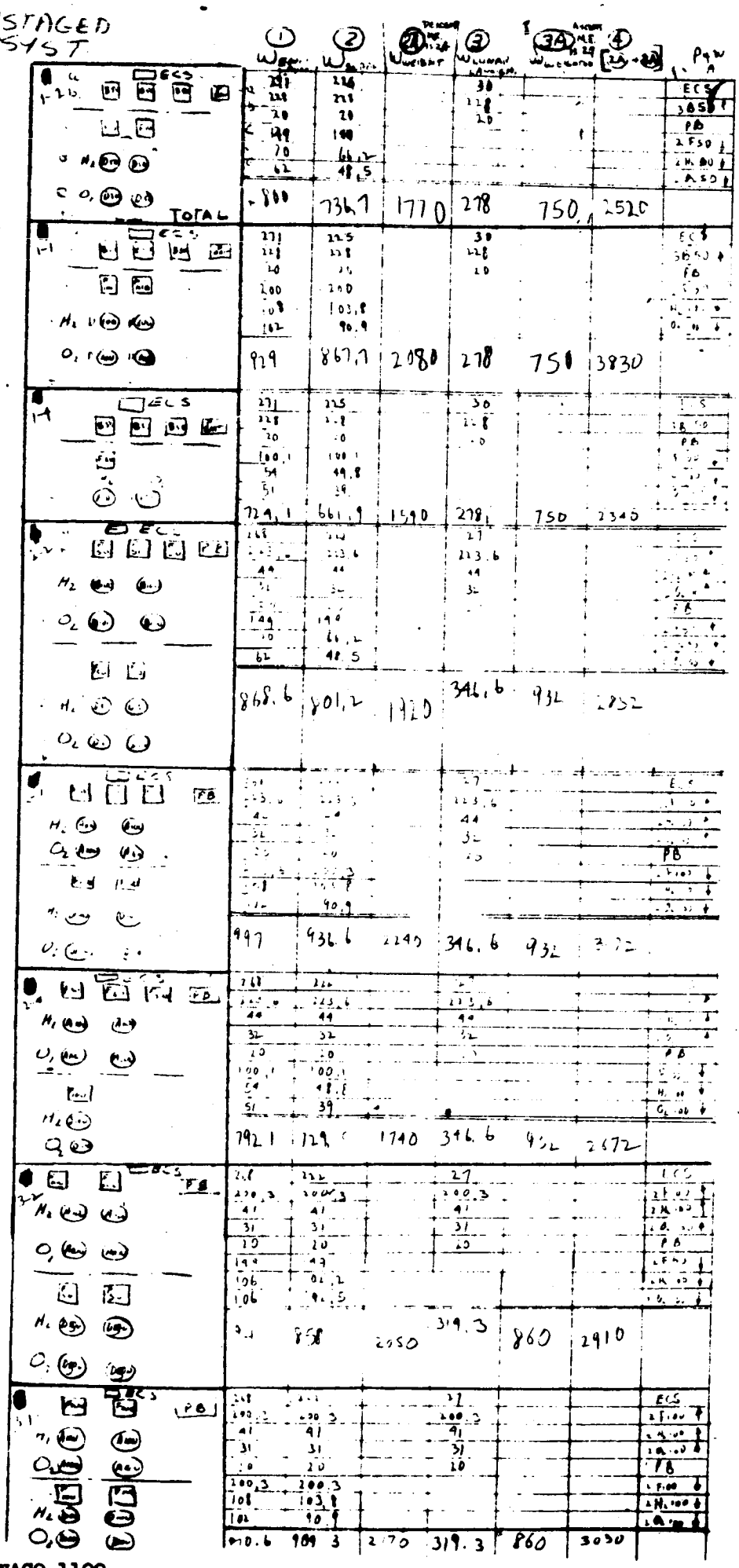
	(1)	(2)	(2A)	(3)	(3A)	(4)	
							P&W A
50 ECS							
	642.3	579	1390	348.6	940	2330	
60 ECS							
	675.1	611.8	1460	377.9	1020	2480	
70 ECS							
	742.4	679.1	1620	449.7	1210	2830	
80							
	658.1	595.8	1420	365.9	995	2405	
90							
	718.3	655	1570	424	1140	2710	
130							
	758.3	696	1670	465.6	1260	2935	



765.4	703.7	1680	319.3	860	2540		
782.	719.3	1720	260 6	705	2925		
806,9	749.7	1790	260.6	705	2495		
706.7	644 5	1540	260 6	705	2245		
829.3	761.1	1820	278	750	2570		
892.9	852.7	1980	346.6	936	2915		
865.6	863.9	1920	319.3	860	2780		

Cont. No. NAS9-1100
Primary Code 008

STAGED SYST



1-2	1-2 TOTAL	1800	1736.7	1770	278	750	2520
1-1		929	867.7	2080	278	750	3830
1-4		729.1	661.9	1590	278	750	2340
2-2		868.6	801.2	1720	346.6	932	2952
2-1		997	936.6	2240	346.6	932	3772
3-4		792.1	729	1740	346.6	932	2672
3-2			858	2050	319.3	860	2910
3-1		910.6	909.3	2170	319.3	860	3050

P&W A

ON STAGED

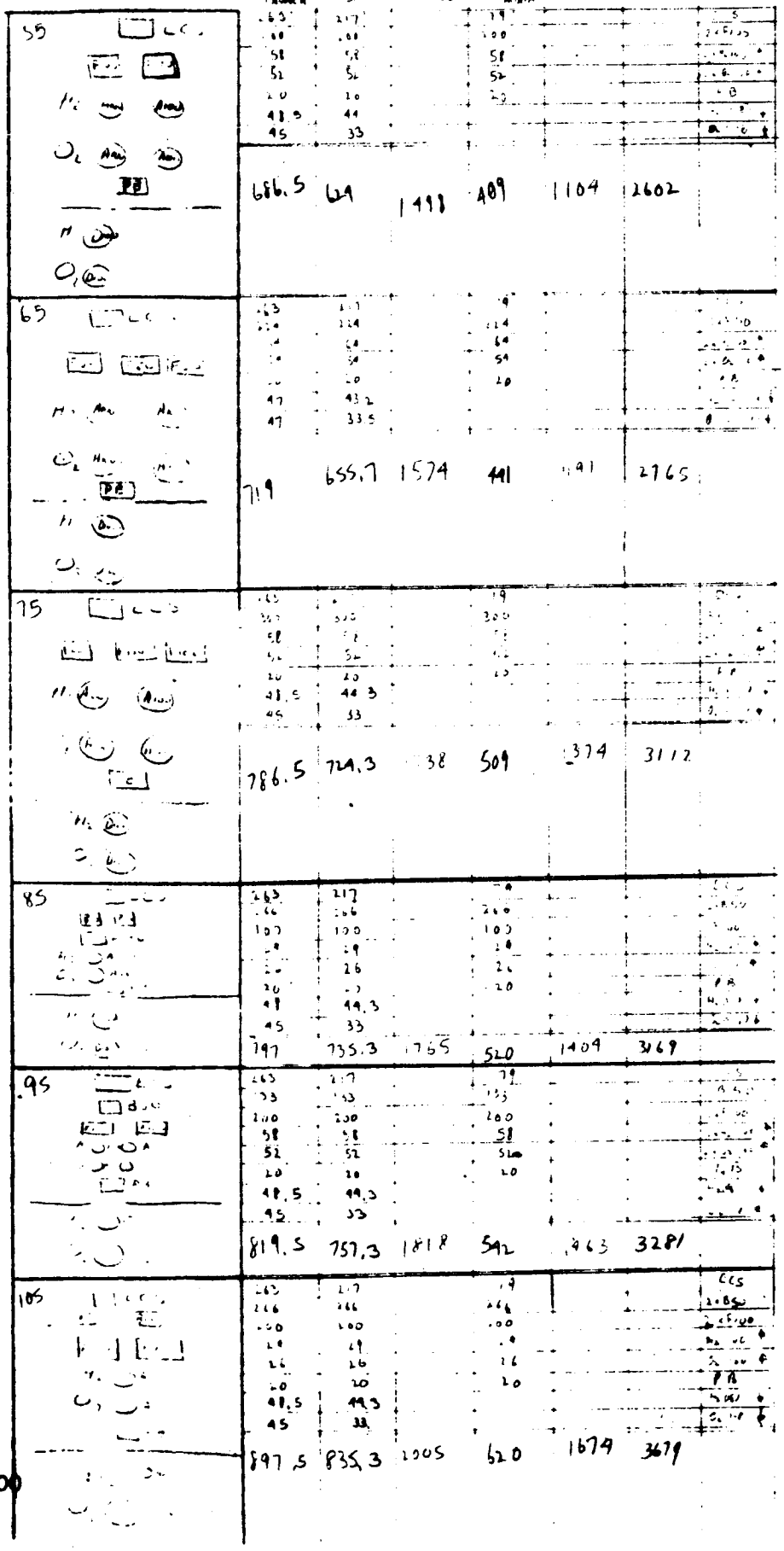
	①	②	2A	③	3A	④	
50 ECS	263	217		79			ECS
	208	200		200			2x500
	59	59,1		45,3			H_2 100
	29	29		29			H_2 (3-m)
	60	49		29,9			O_2 100
	26	26		26			O_2 (3-m)
	20	20		20			P.B
	651	598,8	1429	428,9	1158	2585	
60 ECS	263	217		79			ECS
	339	339		339			3x500
	59	59,1		45,3			H_2 100
	29	29		29			H_2 (3-m)
	63	49,5		30,8			O_2 100
	27	27		27			O_2 (3-m)
	20	20		20			P.B
	687	623,7	1497	458	1237	2734	
70 ECS	263	217		79			ECS
	300	300		300			3x500
	59	59,1		45,3			H_2 100
	29	29		29			H_2 (3-m)
	60	49		29,9			O_2 100
	26	26		26			O_2 (3-m)
	20	20		20			P.B
	757	694,8	1668	529,2	1429	3097	
80 ECS	263	217		79			ECS
	266	266		266			2x500
	100	100		100			5100
	59	59,1		45,3			H_2 100
	60	49		29,9			O_2 100
	20	20		20			P.B
	718	705,8	1694	540,2	1460	3154	
90 ECS	263	217		79			ECS
	133	133		133			6 50
	200	200		200			5100
	59	59,1		45,3			H_2 100
	29	29		29			H_2 (3-m)
	60	49		29,9			O_2 100
	26	26		26			O_2 (3-m)
	20	20		20			P.B
	790	727,8	1747	562,2	1518	3265	
100 ECS	263	217		79			ECS
	266	266		266			2x500
	200	200		200			2x5100
	59	59,1		45,3			H_2 100
	60	49		29,9			O_2 100
	20	20		20			P.B.
	868	805,1	1939	640,2	1720	3454	

RELIABILITY

STAGED TANKAGE

P&W C

P&W C



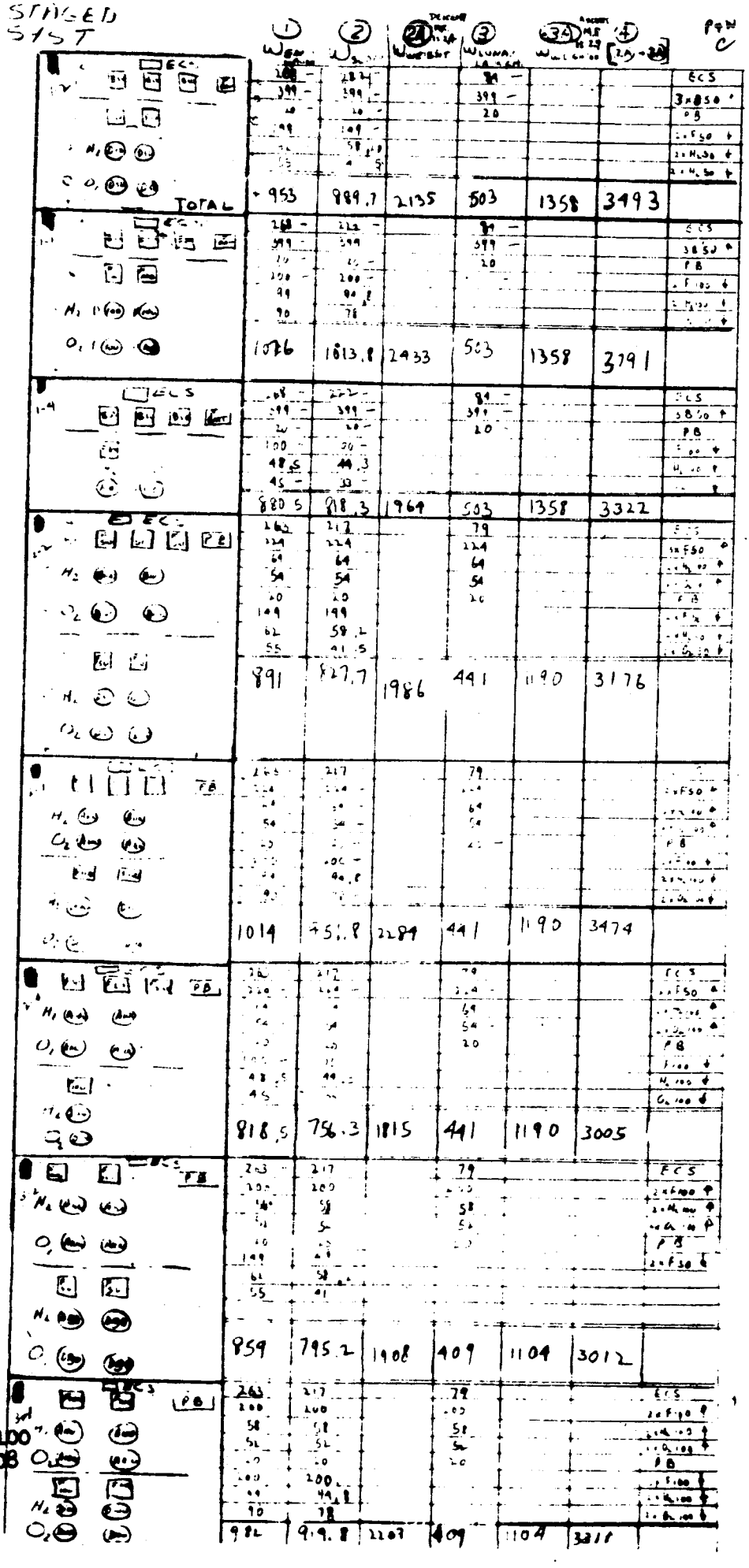
	① W	② W	2A W	③ W	3A W	④ W [2A+3A]
55	686.5	629	1491	489	1104	2602
65	719	655.7	1574	441	1141	2765
75	786.5	724.3	38	509	1374	3112
85	797	735.3	1765	520	1409	3269
95	819.5	757.3	1818	542	1463	3281
105	897.5	835.3	2005	620	1679	3679

P&W "C"

STAGED SYS.

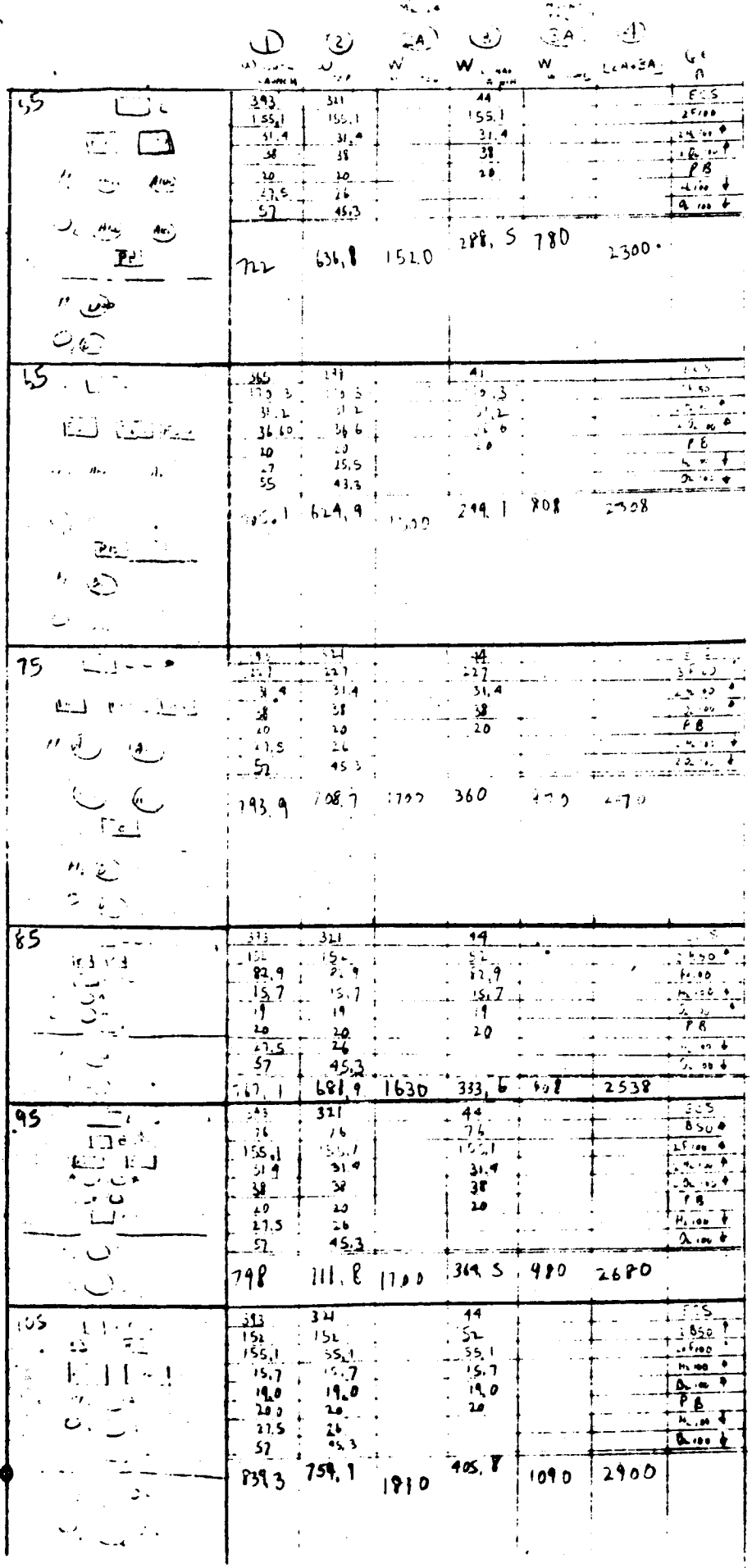
	786.5	726.4	1743	469	1104	2847
	778	719.7	1715	328	886	2601
	805.5	743	1783	328	886	2669
	805.5	743	1543	328	886	2429
	980.5	918	2206	503	1358	3564
	918.5	856	2059	441	1191	3250
	886.5	824.3	1978	469	1104	3082

PEW MISSION C



STAGED TANKAGE

GE "A"



UN STAGED

GE A

GE "A"

	(1)	(2)	(2A)	(3)	(3A)	(4)	CF A
60	315	298		91			ECS
	170.3	170.3		170.3			
	30	28.3		25			
	15.6	15.6		15.6			
	44	51.3		29.5			
	18.3	18.3		18.3			
	20	20		20			
	683.2	603	1450	319.7	849	2298	
70	393	321		45			ECS
	227	227		227			
	30.8	29.3		25.6			
	15.7	15.7		15.7			
	66	55.3		29.7			
	19	19		19			
	20	20		20			
	771.5	687.3	1637	377	1010	2647	
80	393	321		44			ECS
	152	152		152			
	82.9	82.9		82.9			
	30.8	29.3		25.6			
	66	59.3		29.7			
	20	20		20			
	744.7	659.5	1570	349.2	940	2510	
90	393	321		44			ECS
	76	76		76			
	155.1	155.1		155.1			
	30.8	29.3		25.6			
	15.7	15.7		15.7			
	66	55.3		29.7			
	19	19		19			
	20	20		20			
	775.6	691.4	1660	379.1	1020	2680	
100	393	321		44			ECS
	52	152		152			
	155.1	155.1		155.1			
	30.8	29.3		25.6			
	66	59.3		29.7			
	20	20		20			
	816.9	731.7	1750	421.4	1130	2880	

STAGED

GE A

GE "A"

1A	804.9	719.7	1720	288.5	780	2500
2L	811.8	693.6	1660	227.8	615	2275
3	819.4	734.2	1750	385.9	1028	2788
4A	747.2	662	1590	230.8	620	2210
13	866.6	781.4	1870	278	750	2620
2	890.7	805.5	1930	302.1	812	2742
3B	877.1	791.9	1900	288.5	780	2680

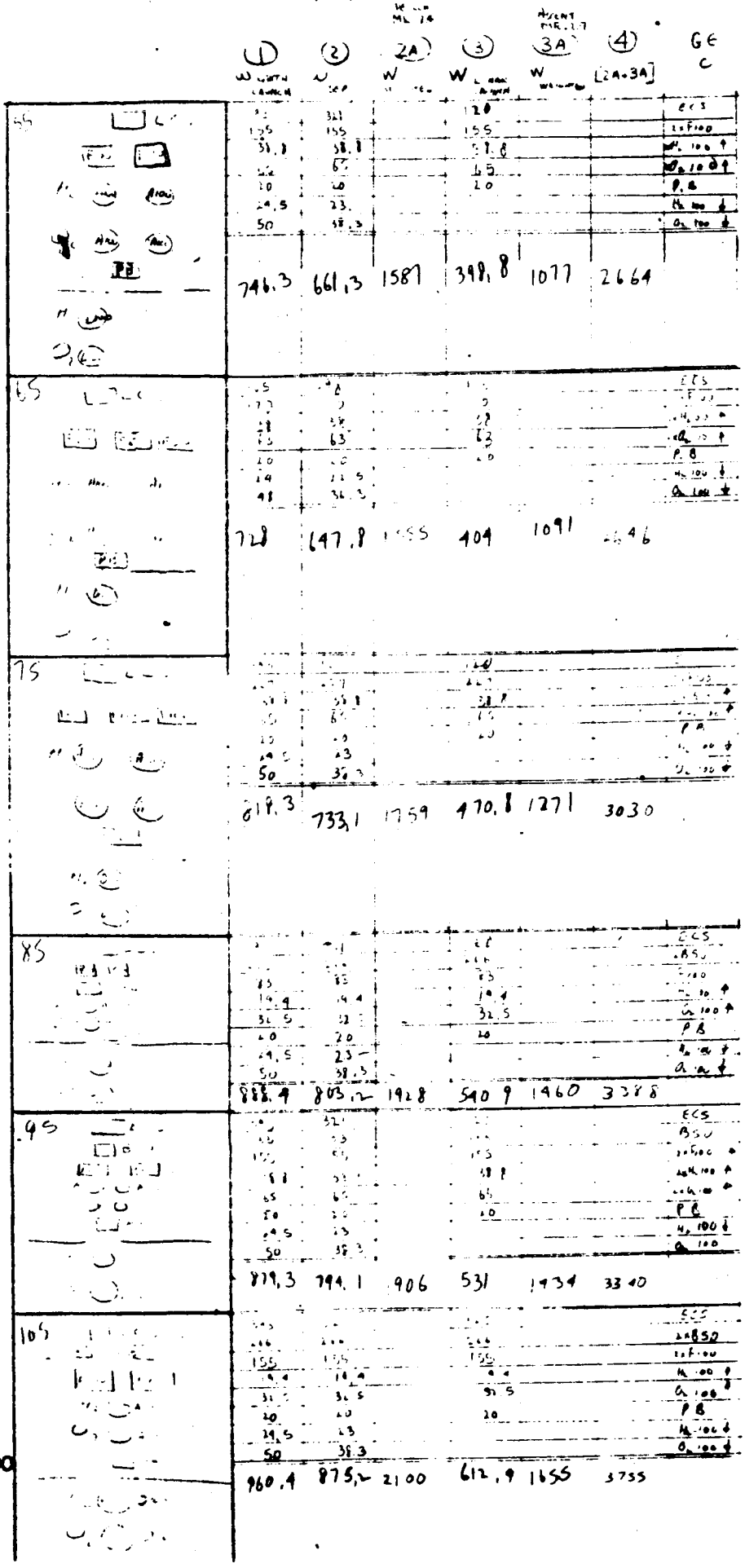
1 STAGED GE SYST.

GE "A"

	(1)	(2)	(2a)	(3)	(3a)	(4)	GE
1-2	+822.0	743.8	1780	278	750	2530	
1-1	951.1	865.9	2070	278	750	2830	
1-9	794.4	709.2	1700	278	750	2450	
2-2	844.1	763.9	1830	299.1	807	2637	
	975.2	890	2130	302.1	816	2946	
	818.5	733.3	1760	302.1	816	2576	
	830.9	750.7	1810	285.5	778	2588	
	914.6	876.9	2100	288.5	778	2878	

STAGED TANKAGE

GE "C"



UN STAGED

	①	②	2A	③	3A	④	
50	393	391		140			ECS
	166	166		166			2×850
	93	93		93			F100
	32	30.5		27.6			H2 100
	19.9	19.9		19.9			O2 (I-T)
	70	69.3		35			O2 100
	32.5	32.5		32.8			O2 (E-T)
	20	20		20			PB
	774.9	696.9	1552	484.5	1100.	2652	
60	365	218		113			ECS
	170	170		170			2×F50
	31	30.5		27.7			H2 100
	19	19		19			O2 (I-T)
	68	56.2		34.8			O2 100
	31.5	31.5		31.5			O2 (E-T)
	20	20		20			PB
	704.5	629.3	1497	415	1121	2619	
70	393	32		120			ECS
	227	227		227			2×F100
	32	30.5		27.6			H2 100
	19.4	19.4		19.9			O2 (I-T)
	70	68.3		35			O2 100
	32	32.5		32.6			O2 (E-T)
	20	20		20			PB
	793	718.7	1725	484.5	1300	3025	
80	393	32		120			ECS
	266	266		266			2×850
	93	93		93			F100
	32	30.5		27.6			H2 100
	70	69.3		35			O2 100
	20	20		20			PB
	814	788.8	1893	551.6	1489	3382	
90	393	32		120			ECS
	133	133		133			850
	155	155		155			2×F100
	32	30.5		27.6			H2 100
	19.4	19.4		19.4			O2 (I-T)
	70	69.3		35.0			O2 100
	31.5	32.8		31.5			O2 (E-T)
	20	20		20			PB
	859.9	779.7	1871	542.5	1465	3336	
100	393	32		120			ECS
	266	266		266			2×850
	155	155		155			2×F100
	32	30.5		27.6			H2 100
	70	69.3		35			O2 100
	20	20		20			PB
	936	860.8	2066	623.6	1689	3758	

Contract No. NAS9-1100
Primary Code 008

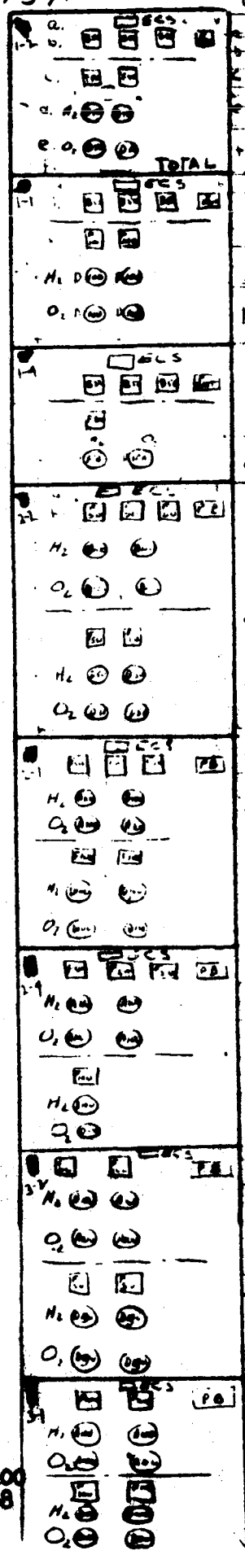
RELIABILITY

GE

MISSION C

STAGED SYS

| | | |



1-2	965.0	994.1	2120	503	1357	3477	TOTAL
1-1	1081	995.8	2390	503	1357	3747	
1-4	944.5	849.3	2030	503	1357	3387	
2-2	865	785.8	1884	409	1091	2975	
2-1	988	902.8	2167	411	1110	3277	
2-4	241.5	756.3	1815	411	1110	2925	
3-V	952.8	772.6	2054	391.8	1050	2904	
3-1	975	890.6	2138	391.8	1050	3215	

GE

MISSION C

STAGED TANKAGE

AC
A

A-C
MISSION A

	①	②	2A	③	3A	④	Ac
	W (with launch)	W (stage)	W (without)	W (stage launch)	W (without)	[2A+3A]	A
55	387	387		45			ECS
	187	187		187			2 F100
	30	30		30			2 H2 P
	30	30		30			2 O2 P
	20	20		20			PB
	26.2	29.9					2 H2
	53.5	43					2 O2
		652.9	1570	312	841	2411	
65	387	387		45			ECS
	178	178		178			3F50
	30	30		30			
	30	30		30			
	20	20		20			PB
	26.2	29.9					
	53.5	43					
		643.9	1550	303	820	2370	
75	387	387		45			ECS
	277	277		277			
	30	30		30			
	30	30		30			
	20	20		20			PB
	26.2	29.9					
	53.5	43					
		742.9	1590	402	970	2860	
85	387	387		45			ECS
	152	152		152			2B50
	97	97		97			
	15	15		15			
	15	15		15			
	20	20		20			PB
	26.2	29.9					
	53.5	43					
		689.9	1640	349	928	2568	
95	387	387		45			ECS
	76	76		76			B50
	187	187		187			2F100
	30	30		30			
	30	30		30			
	20	20		20			PB
	26.2	29.9					
	53.5	43					
		1289	1750	388	1050	2800	
105	387	387		45			ECS
	152	152		152			2B50
	187	187		187			2F100
	15	15		15			
	15	15		15			
	20	20		20			PB
	26.2	29.9					
	53.5	43.0					
		1149	1860	439	1170	3030	

UNSTAGED

AC
A

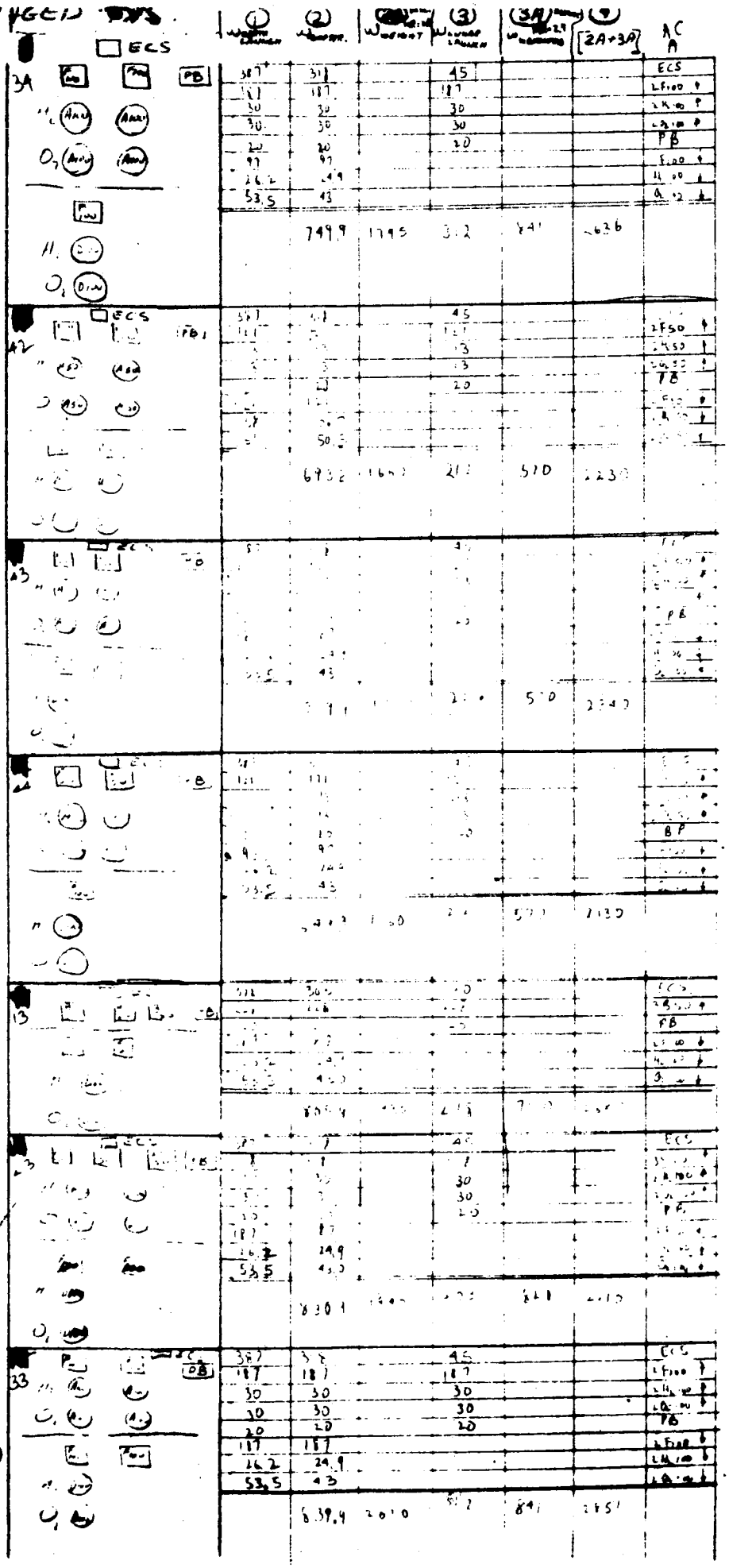
A-C

MISSION A

	①	②	2A	③	3A	④	AC A
50 ECS PB H_2 O_2	387	318		45			ECS
	177	177		177			SFC
	44.5	43.2		39.9			H_2
	80.4	69.9		43.6			O_2
	20	20		20			PB
		638.1	1530	335.5	905	2435	
60 ECS PB FC1 FC2 H_2 O_2 PB	387	318		45			ECS
	178	177		178			SFC
	44.5	43.2		39.9			H_2
	80.4	69.9		43.6			O_2
	20	20		20			PB
		629.1	1510	326.5	880	2390	
70 ECS PB FC1 FC2 H_2 O_2 PB	387	318		45			ECS
	177	177		177			SFC
	44.5	43.2		39.9			H_2
	80.4	69.9		43.6			O_2
	20	20		20			PB
		728.1	1740	425.4	1145	2985	
80 ECS PB FC1 FC2 H_2 O_2 PB	387	318		45			ECS
	152	152		152			ASD
	97	97		97			FC
	29	27.7		24.9			H_2
	62.2	51.7		36.8			O_2
	20	20		20			PB
		666.4	590	375.2	1040	2600	
90 ECS PB FC1 FC2 H_2 O_2 PB	387	318		45			ECS
	76	76		76			ASD
	177	187		177			SFC
	44.5	43.2		39.9			H_2
	80.4	69.9		43.6			O_2
	20	20		20			PB
		714.1	1710	411.5	1110	2820	
100 ECS PB FC1 FC2 H_2 O_2 PB	387	318		45			ECS
	152	152		152			ASD
	187	187		187			SFC
	29	27.7		24.9			H_2
	62.2	51.7		36.8			O_2
	20	20		20			PB
		756.4	1810	465.2	1250	3060	

A-C

MISSION A



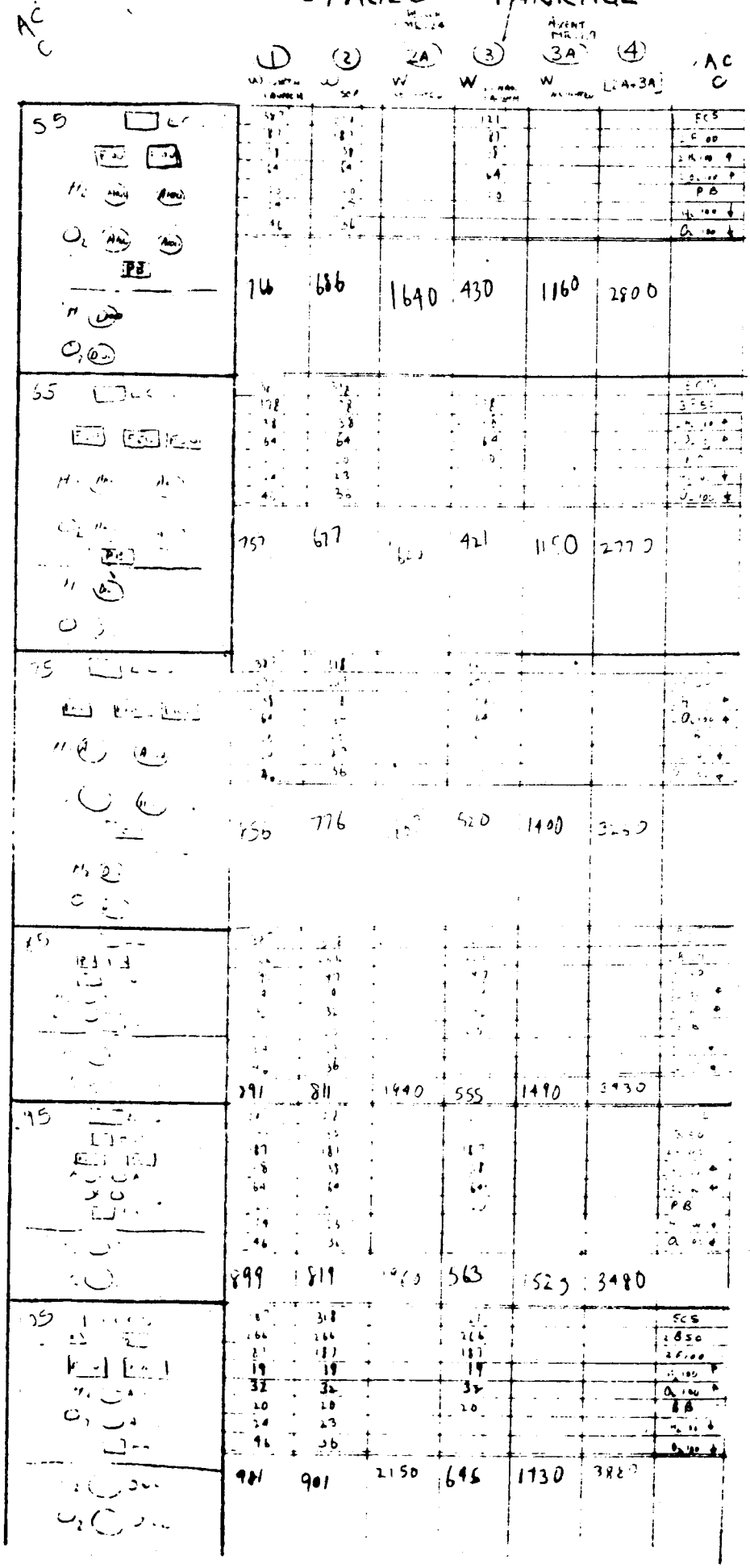
STAGED SYST.

(1) W Expd.	(2) W Dry	(2A) ME Weight	(3) W Usable	(3A) ME Weight	(4) (2A)+(3A)	AC A
372	303		30			ECS
228	228		228			3850
20	20		20			PB
187	187					2F150
38	34.7					2H2
61	50.5					2O2
890	759.2	1820	278	750	2570	TOTAL
372	303		30			ECS
228	228		228			3850
20	20		20			PB
187	187					2F100
52.4	51.1					2H2
107	96.5					2O2
966.9	885.6	2120	278	750	2870	
372	303		30			ECS
228	228		228			3850
20	20		20			PB
187	187					2F100
26.2	24.9					H2
53.5	43					O2
	715.9	[illegible]	[illegible]	[illegible]	2460	
317	318		45			ECS
178	178		178			3F50
30	30		30			2H2
30	30		30			2O2
20	20		20			PB
[illegible]	[illegible]					2F50
[illegible]	[illegible]					2H2
[illegible]	5.5					2O2
	[illegible]	1880	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]		45			ECS
[illegible]	[illegible]		[illegible]			3F50
[illegible]	[illegible]		30			2H2
[illegible]	[illegible]		30			2O2
[illegible]	[illegible]					PB
[illegible]	[illegible]					2F50
[illegible]	[illegible]					2H2
[illegible]	96.5					2O2
	710.6	[illegible]	303	[illegible]	2[illegible]	
[illegible]	[illegible]		45			ECS
[illegible]	[illegible]		[illegible]			3F50
[illegible]	30		30			2H2
30	30		30			2O2
20	20		20			PB
91	91					F100
26.2	24.9					H2
53.5	43					O2
	749.9	[illegible]	303	[illegible]	2.00	
317	318		45			ECS
187	187		187			2F100
[illegible]	30		30			2H2
30	30		30			2O2
20	20		20			PB
[illegible]	[illegible]					[illegible]
[illegible]	[illegible]					[illegible]
[illegible]	51.1					[illegible]
	793.2	1900	312	891	2741	
317	318		45			ECS
187	187		187			2F100
30	30		30			2H2
30	30		30			2O2
20	20		20			PB
187	187					2F100
52.4	51.1					2H2
107	96.5					2O2
	919.6	2200	312	891	3091	

A-C

MISSION A

STAGED TANKAGE



A-C

MISSION C

AC C 1

UN STAGED

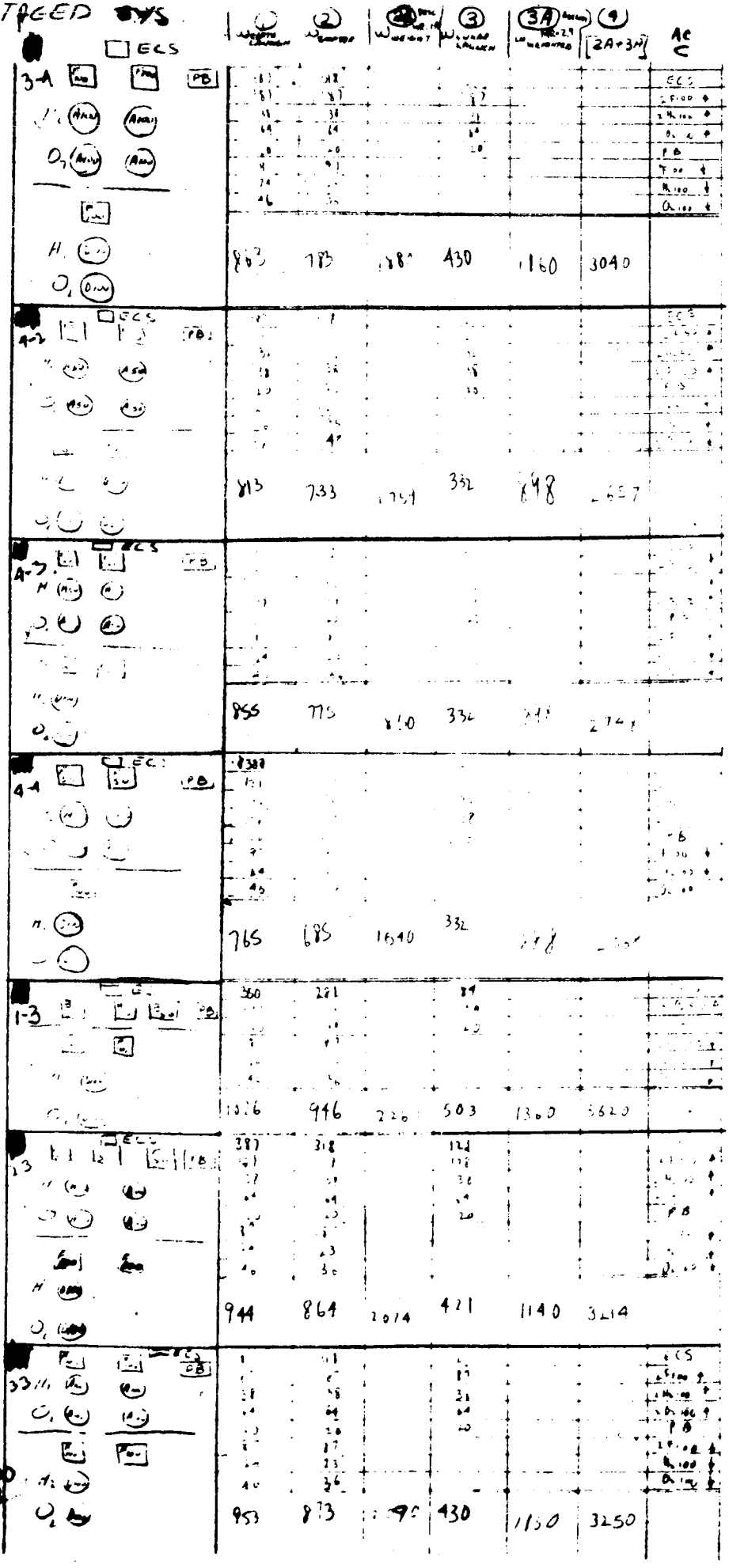
	①	②	2A (Dec MR=2.4)	③	3A (Aeroj MR=2.9)	④ [2A+3A]	AC C
80 ECS PB	745	662	1580	441	1190	2770	
60 ECS PB	733	653	1560	432	1165	2725	
70 ECS PB	832	752	1800	531	1430	3230	
80 ECS PB	887	787	1880	566	1530	3410	
90 ECS PB	875	795	1900	574	1550	3450	
100 ECS PB	951	877	2100	656	1720	3870	

ALLIS-C
MISS C

RELIABILITY
MISSION
CREW SAFETY

A-C

MISSION C



RELIABILITY

A·C

MISSION C

AC STAGED SYST

	(1) W_{gw}	(2) W_{lw}	(2A) Descent Wt	(3) W_{Lunar}	(3A) Ascent Wt	(4)	(2A)-(4)	AC
	350	281		84				ECS
	399	384		389				3850 P
	20	20		20				PB
	124	124						2F50 ↓
	6	33						2H2 50 ↓
	53	49						2O2 50 ↓
TOTAL	976	904	2160	503	1360	3520		
	350	281		84				ECS
	399	384		389				3850 P
	20	20		20				PB
	124	124						2F 50 ↓
	47	33						2H2 100 ↑
	92	82						2O2 100 ↑
	1095	1015	2420	503	1360	3780		
	350	281		84				ECS
	399	384		389				3850 P
	20	20		20				PB
	61	37						100 ↓
	39	33						H2 100 ↑
	26	26						O2 100 ↑
	936	856	2092	503	1360	3400		
	91	81		1				ECS
	24	24		25				2F50 ↓
								2H2 100 ↑
								2O2 100 ↑
								PB
								2F 50 ↓
	55	55						2H2 50 ↓
	48	48						2O2 50 ↓
	902	822	1973	424	1139	3139		
	318	318		1				ECS
	187	187		25				2F50 ↓
	38	38		54				2H2 100 ↑
	64	64		20				2O2 100 ↑
	20	20						PB
	121	121						2F 50 ↓
	36	36						2H2 50 ↓
	58	48						2O2 50 ↓
	913	933	2339	424	1137	3376		
	318	318		121				ECS
	187	187		38				2F50 ↓
	38	38		64				2H2 100 ↑
	64	64		20				2O2 100 ↑
	20	20						PB
	121	121						2F 50 ↓
	36	36						2H2 50 ↓
	58	48						2O2 50 ↓
	859	774	1858	424	1137	2995		
	318	318		121				ECS
	187	187		38				2F50 ↓
	38	38		64				2H2 100 ↑
	64	64		20				2O2 100 ↑
	20	20						PB
	121	121						2F 50 ↓
	36	36						2H2 50 ↓
	58	48						2O2 50 ↓
	911	831	1999	430	1160	3150		
	318	318		121				ECS
	187	187		38				2F50 ↓
	38	38		64				2H2 100 ↑
	64	64		20				2O2 100 ↑
	20	20						PB
	121	121						2F 50 ↓
	36	36						2H2 50 ↓
	58	48						2O2 50 ↓
	911	831	1999	430	1160	3150		

APPENDIX "D"

THERMODYNAMICS EVALUATION OF ENERGY CONVERSION UNITS

Summary

The following is an evaluation, from a standpoint of thermodynamic and thermal performance, of the LEM power supply proposals submitted by Pratt and Whitney, Sundstrand, Allis-Chalmers, and General Electric. The proposals are discussed in order of their preference from a thermodynamics standpoint.

1. Pratt and Whitney
2. General Electric
3. Allis-Chalmers
4. Sundstrand

Discussion

1. Pratt and Whitney Fuel Cell

This power supply system is an open cycle, hydrogen-oxygen fuel cell. The thermal energy generated by the fuel cell is carried overboard by the use of excess hydrogen. The thermal design of this unit, as presented by Pratt and Whitney is compatible with the LEM vehicle and mission. A major advantage of this unit is that, since the ECS is not used for cooling, a failure of the ECS will not result in a failure of the EPSS. Also, the 500°F operating temperature of the unit is ideal for the addition of a space radiator to accommodate an extension of the mission. The high ($\geq$ 300°F) case temperatures of this fuel cell will require the cells to be insulated in order that there is no adverse effect on cryogenic tankagezor electronic equipment.

2. General Electric Fuel Cell

This power supply is a closed cycle, hydrogen-oxygen fuel cell. This fuel cell differs from the Pratt and Whitney fuel cell in that it operates at $\approx$ 130°F. The thermal energy generated by the fuel cell is carried away by the LEM ECS. The thermal design of this unit, as presented by General Electric, is compatible with the LEM vehicle and mission. The major disadvantages of this unit are that it is more complex than the Pratt and Whitney fuel cell and that, since it is cooled by the ECS, a failure of the ECS will also result in a loss of vehicle electric power generation. (i.e. unless backup batteries are used.)

Appendix "D" Continued

3. Allis-Chalmers Fuel Cell

This power supply system is a closed cycle, hydrogen-oxygen fuel cell similar to the General Electric unit. The thermal energy generated by the fuel cell is partly carried away by the LEM ECS and partly dumped overboard by venting the water produced by the cell to space. Since A-C did not include a detailed thermal analysis in their proposal, it is impossible for the Thermodynamics Group to comment on it. However, it should be pointed out that the thermal design of this fuel cell is quite straightforward. The proposed venting of water overboard has not been explained in sufficient detail for the thermal group to determine if the method proposed is feasible. It is true that if the water produced by this fuel cell were evaporated to space approximately one-third of the heat generated by the fuel cell would be removed; however, Allis-Chalmers has not explained in detail how they intend to do it. The weight of an evaporator and its controls should probably be added in the future evaluations of this unit. This fuel cell also has the disadvantage that a failure of the ECS will result in a loss of vehicle electric power generation. In a direct comparison with the Pratt and Whitney and General Electric fuel cell proposals, Allis-Chalmers seems not to be as advanced in the design of a LEM-type power supply system at this time.

4. Sundstrand - Cryhocycle

This power supply system is a closed cycle hydrogen expansion engine which incorporates the ECS with the EPSS. At the present time, the Thermodynamics Group has not been presented with sufficient proof of the feasibility of the proposed Cryocycle to warrant endorsing it as a possible LEM power supply system.

Although continuously questioned by Grumman, Sundstrand has been unable to justify their assumptions of high mechanical efficiencies and high heat transfer coefficients in the Cryhocycle. More realistic mechanical efficiencies will result in an increase in specific hydrogen consumption, tankage weight, hydrogen weight, etc. Sundstrands's choice of heat transfer coefficients in the expansion cylinders are extremely high. (i.e. approximately 100 to 500 times the values calculated by Grumman and corroborated in consultation with heat transfer authorities outside the Grumman Company). The use of realistic heat transfer coefficients will again result in an increase in specific hydrogen consumption, tankweight, and hydrogen weight as well as the addition of at least one hydrogen/to/glycol heat exchanger with its associated plumbing. The combined increase in weight due to lower heat transfer coefficients may well be 100 pounds or more.

Many thermodynamic and mechanical design questions were asked of Sundstrand dueing the study. Listed below are the Sundstrand answers to several pertinent questions.

Appendix "D" Continued

4. GAEC QUESTIONS	* Sundstrand ANSWERS
(a) What is the weight change by eliminating the polytropic expansion (weight changes include heat exchanger increase, reciprocator decrease and propellant increase)?	(a) +49 pounds (Mission "A")
(b) Changing integrated P-V diagram from 97% to 92% of theoretical?	(b) 26 pounds
(c) Lowering generator efficiency curve to 85% maximum? (At maximum output)	(c) 14 pounds
(d) Lowering mechanical efficiency curve to 85% maximum? (Keeping constant friction horsepower with decreasing load.)	(d) 14 pounds

NOTE: * All weight increases.

As noted previously, by failing to meet all the estimated performance goals, the cryhocycle weight adjustment approaches 100 pounds. This is a possibility considering the present cryhocycle development status. A development program is required to determine the validity of the performance claimed by the cryhocycle approach. This lack of development precludes its further consideration for the LEM EPS.

3. Optimum system weights.

4. Adequate failure protection.

5. Maximum simplicity.

6. Inherent automatic switchover in the event of system failure.

APPENDIX E - TANKAGE AND FLUID FEED SYSTEM

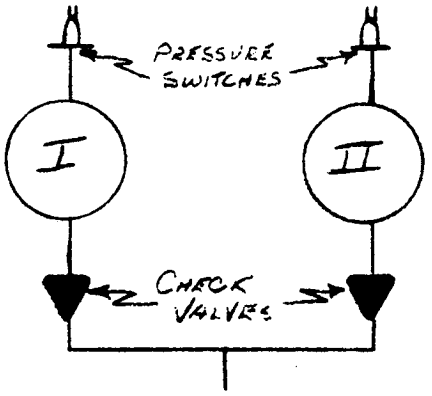
For the purpose of the study, a two-tank system was assumed.

The following assumptions were made:

1. If one tank failed, it would result in an immediate abort or mission curtailment.

2. There was no vehicle center-of-gravity problem which required the tanks to be parallel-fed.

TANK FEED SYSTEM



In the sequential feed system shown above, the control pressure switch of Tank I is set at a higher setting than Tank II, thereby keeping the Tank II discharge check valve closed. If Tank I ceases to feed, then Tank II will immediately supply fluid to the system.

TANK SIZING

The basic tank quantities arrived at for the two-tank configuration was:

1 - 100% Tank
2 - Phase 8 to 11 Tank

The above configuration would supply the normal system requirements during the mission from the 100% tank. In the event of a failure of that tank, the phase 8 to 11 (ascent) tank would supply fluid. In the event of a failure of the ascent tank, a mission curtailment or abort would be performed on the 100% tank.

This system was assumed adequate, based on the following:

1. Small total fluid quantities involved.

2. Low flow rates.

APPENDIX F - EFFECT OF REMOVING TRANSLUNAR ENERGY REQUIREMENTS ON THE LEM EPS SYSTEM

Table 11 illustrates the actual system weight reductions that will result by removing the translunar 12.1 KW-hr requirements.

The average actual reduction is approximately 30.

TABLE 11 - WEIGHT EFFECT OF REMOVING TRANSLUNAR ENERGY REQUIREMENTS (MISSION "C")

	Fuel Cells		Cryhocycle
	Bacon	Ion-Membrane	
Oxygen decrease	3.2	1.2	3.5
Hydrogen decrease	11.9	9.7	15.5
Total Fluid System decrease (including tank effect)	24	15	35
Cooling Water decrease	(3)=increase	20	--
Total Actual Weight	21	35	35

TABLE V-1

ECS & PGS COOLING WATER REQUIREMENTS
(MISSIONS "A" & "C")

	ECS REQ'D COOLING WATER	G.E. 100% Mod "A"	G.E. 100% Mod "C"	G.E. 50% Mod "A"	G.E. 50% Mod "C"	ALLIS-C "A"	ALLIS-C "C"	P.W. "A"	P.W. "C"	CRYHO "A"	CRYHO "C"
WGT. @ EARTH LAUNCH	283	110	110	81.6	81.6	104	104	-15	-20		-283
@ SEPARATION	233	88	88	65	65	85.2	85.2	-11	-16		-233
@ LUNAR LAUNCH	"A" "C" 29.6 84	14.7	35.4	11	29	15.1	37.2	-2.7	-4.6	-29.6	-84

NOTES: -(1) GE WEIGHTS ADJUSTED FOR WATER PRODUCED & RECLAIMED.

(2) ALL SYSTEMS WEIGHTS ADJUSTED FOR COOLING PRODUCED BY CYROGENIC HEAT EXCHANGER, RESULTING IN SMALLER ECS WATER WEIGHTS.

TABLE V-2

TOTAL COOLING WATER REQUIREMENTS
(MISSIONS "A" & "C")

		G E 100% Mod		G E 50% Mod		ALLIS-C		P. W.		CRYHO	
		"A"	"C"	"A"	"C"	"A"	"C"	"A"	"C"	"A"	"C"
WGT.	● EARTH LAUNCH	393	393	364.6	364.6	387	387	263	263	0	0
	● SEPARATION	321	321	298	298	318.2	318.2	222	217	0	0
	● LUNAR LAUNCH	44.3	119.4	113	113	44.7	121.2	26.9	79.4	0	0

TABLE V-3 FUEL CELLS & BATTERY MATRIX

		1	2	3	4	5	6	7	8	9	10	11	12
STAGED	ASCENT	☐ ☐ ☐ TA-2	☐ TA-2 ☐ TA-3 ☐ TA-4	☒ ☒	☒ ☒ ☒	☒ ☒	☒ ☒ ☒	☒ ☒ ☒	☒ ☒ ☐	☒	☐ TA-1 ☐ TA-2 TA-4 TA-5	☐ TA-1 ☐ TA-2 TA-4 TA-5	☐ TA-1 ☐ TA-2 ☐ TA-4 TA-5
	DESCENT	☐ ☐ TA-2	☐ TA-1 ☐ TA-2 ☐ TA-4	☐ TA-1 ☐ TA-2 TA-4	☐ TA-1 ☐ TA-2 TA-4	☐ TA-1 ☐ TA-2 ☐ TA-4	☐ ☐ TA-5	☐ TA-1	☐ TA-2 ☐	☒ ☒	☐ TA-1 TA-2 TA-4	☐ TA-1 ☐ TA-2 TA-4	☐ TA-1 ☐ TA-2 ☐ TA-4
UNSTAGED	ASCENT	☐ TA-2 ☐ TA-3 TA-4	☐ TA-2 ☐ TA-3 ☐ TA-4	☐ TA-1 ☒ TA-2 ☐ TA-3 ☐ TA-4	☐ TA-1 ☒ TA-2 ☒ TA-3 ☒ TA-4	☐ TA-1 ☐ TA-2 ☒ TA-3 ☒ TA-4	☐ TA-1 ☐ TA-2 ☐ TA-3 ☒ TA-4	☒	☒ ☒				
	DESCENT	—	—	—	—	—	—	—	—				
STAGED TANKAGE	ASCENT	☐ TA-2 ☐ TA-4	☐ TA-2 ☐ TA-3 ☐	☐ TA-1 ☒	☐ TA-1 ☐ ☒								
	DESCENT	TA-1 TA-2 TA-3	TA-1 TA-2 TA-3	TA-1 TA-2 TA-4	TA-1 TA-2 TA-3								

ENERGY CONVERSION DEVICE

☐ FUEL CELL OR ENGINE

☒ BATTERY

TANKAGE ARRANGEMENT

100% ⊗

50% ⏃

ASCENT & RENDEZ ○

	O_2	H_2
TA-1	⊗	⊗
TA-2	⊗⊗	⊗⊗
TA-3	⊗○	⊗○
TA-4	⏃⏃⏃	⊗⊗
TA-5	⏃⏃	⏃⏃

Contract No. NAS9-1180
Primary Code 008

Report LED-390-2
Date 1 April 1963

TABLE V-4

Summary of Weights for Staged Tankage vs. Unstaged Systems

		Conf.	Staged Tankage	Conf.	Unstaged	Difference (Staged Tankage is basis)
P & W	A	55	2310	50	2330	+ 20
		65	2440	60	2480	+ 40
		75	2810	70	2830	+ 20
		85	2380	80	2405	+ 25
		95	2680	90	2710	+ 30
		105	2890	100	2930	+ 40
P & W	C	55	2602	50	2585	- 17
		65	2765	60	2734	- 31
		75	3112	70	3097	- 15
		85	3169	80	3154	- 15
		95	3281	90	3265	- 16
		105	3679	100	3654	- 25
G.E.	A	55	2300	50	2292	- 8
		65	2308	60	2298	- 10
		75	2670	70	2647	- 23
		85	2538	80	2510	- 28
		95	2680	90	2680	0
		105	2900	100	2880	- 20
G.E.	C	55	2664	50	2652	- 12
		65	2646	60	2619	- 27
		75	3030	70	3025	- 5
		85	3388	80	3382	- 6
		95	3340	90	3336	- 4
		105	3755	100	3750	- 5
A.C.	A	55	2411	50	2435	+ 24
		65	2370	60	2390	+ 20
		75	2860	70	2885	+ 25
		85	2568	80	2600	+ 32
		95	2800	90	2820	+ 20
		105	3030	100	3060	+ 30
A.C.	C	55	2800	50	2770	- 30
		65	2770	60	2725	- 45
		75	3260	70	3230	- 30
		85	3430	80	3410	- 20
		95	3480	90	3450	- 30
		105	3880	100	3870	- 10
S	A	55	1845	50	1960	+115
		65		60		
		75	2206	70	2323	+117
		85	2100	80	2210	+110
		95	2380	90	2500	+120
		105	2460	100	2580	+120
S	C	55	2230	50	2400	+ 70
		65		60		
		75	2580	70	2750	+170
		85	3110	80	3280	+170
		95	3330	90	3490	+160
		105	3470	100	3630	+160

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TABLE V 5

Comparison of Unstaged Configurations

All Fuel Cells vs. Fuel Cells + Battery Combinations

	FUEL CONF.	CELLS EFF. WT	FC + CONF.	BATT EFF. WT.
	50	2585	80	3154
P & W	60	2734	90	3265
	70	3097	100	3654
	Average	2805	Average	3358
		Average 553		
	50	2652	80	3382
GE	60	2619	90	3336
	70	3025	100	3750
	Average	2765	Average	3486
		Average 721		
	50	2770	80	3410
AC	60	2725	90	3450
	70	3230	100	3870
	Average	2908	Average	3577
		Average 669		
	50	2400	80	3280
S	60		90	
	70	2750	100	3630
	Average	2575	Average	3455
		Average 980		

TABLE V 6

Summary of Staged System Configurations

	1	2	3	4
ASCENT	3-B50%	3-F50% 2-A100%-O_2 2-A100%-H_2	2-F100% 2-A100%-O_2 2-A100%-H_2	2-F50% 2-A50%-O_2 2-A50%-H_2

	1	2	3	4
DESCENT	2-F100% 2-D100%-O_2 2-D100%-H_2	2-F100% 2-D50%-O_2 2-D50%-H_2	2-F100% 1-D100% 1-D100%-H_2	1-F100% 1-D100% 1-D100%-H_2

TABLE V 8

EFFECTIVE WEIGHT TABULATION OF

STAGED SYSTEMS (Mission C)

	Conf. Nos.	Eff. Wt.	Conf. Nos.	Eff. Wt.	Conf. Nos.	Eff. Wt.	Conf. Nos.	Eff. Wt.
P & W								
	1-1	3791	2-1	3474	3-1	3311	4-1	___
	1-2	3493	2-2	3176	3-2	3012	4-2	2601
	1-3	3564	2-3	3245	3-3	3082	4-3	2669
	1-4	3322	2-4	3005	3-4	2847	4-4	2429
G E								
	1-1	3747	2-1	3277	3-1	3215	4-1	___
	1-2	3477	2-2	2975	3-2	2904	4-2	2556
	1-3	3557	2-3	3098	3-3	3036	4-3	2679
	1-4	3387	2-4	2925	3-4	2862	4-4	2498
A C								
	1-1	3780	2-1	3376	3-1	3422	4-1	___
	1-2	3520	2-2	3110	3-2	3150	4-2	2657
	1-3	3620	2-3	3214	3-3	3250	4-3	2748
	1-4	3400	2-4	2995	3-4	3040	4-4	2538
S								
	1-1	3640	2-1	___	3-1	3030	4-1	___
	1-2	___	2-2	___	3-2	___	4-2	___
	1-3	3200	2-3	___	3-3	2600	4-3	___
	1-4	3030	2-4	___	3-4	2420	4-4	___

TABLE V 9

EFFECTIVE WEIGHT TABULATION OF
STAGED SYSTEMS (Mission A)

	Conf. Nos.	Eff. Wt.	Conf. Nos.	Eff. Wt.	Conf. Nos.	Eff. Wt.	Conf. Nos.	Eff. Wt.
P & W								
	1-1	3830	2-1	3172	3-1	3030	4-1	____
	1-2	2520	2-2	2852	3-2	2910	4-2	2425
	1-3	2570	2-3	2915	3-3	2780	4-3	2495
	1-4	2340	2-4	2672	3-4	2540	4-4	2245
G E								
	1-1	2830	2-1	2946	3-1	2878	4-1	____
	1-2	2530	2-2	2637	3-2	2588	4-2	2275
	1-3	2620	2-3	2742	3-3	2680	4-3	2788
	1-4	2450	2-4	2576	3-4	2500	4-4	2210
A C								
	1-1	2870	2-1	2900	3-1	3041	4-1	____
	1-2	2570	2-2	2700	3-2	2741	4-2	2230
	1-3	2680	2-3	2810	3-3	2851	4-3	2340
	1-4	2460	2-4	2600	3-4	2636	4-4	2130
S								
	1-1	2618	2-1	____	3-1	2705	4-1	____
	1-2	____	2-2	____	3-2	____	4-2	____
	1-3	2118	2-3	____	3-3	2210	4-3	____
	1-4	1953	2-4	____	3-4	2045	4-4	____

TABLE V 10

Weight and Relative Reliability Comparison
Of Staged and Unstaged Configurations

(Mission C)

Configuration		Effective Weight	Crew Safety Reliability	Mission Completion Reliability
	50	2585	.999578	.973081
Unstaged	60	2734	.999982	.997552
	70	3097	.999982	.997552
P & WA	22	3176	.999982	.971632
	24	3005	.999982	.978686
Staged	32	3012	.999578	.948450
	34	2847	.999578	.954678
	42	2601	.999578	.943856
	44	2429	.999578	.955596
	50	2652	.995311	.946399
Unstaged	60	2619	.999766	.988269
	70	3025	.999766	.988269
	22	2975	.999766	.935620
G. E.	24	2925	.999766	.946859
Staged	32	2904	.995311	.895831
	34	2862	.995311	.905934
	42	2556	.995311	.895912
	44	2498	.995311	.906894
	50	2770	.999232	.927773
Unstaged	60	2725	.999549	.958435
	70	3230	.999549	.958435
	22	3110	.999549	.893934
A. C.	24	2995	.999549	.921985
	32	3150	.999232	.896521
Staged	34	3040	.999232	.896352
	42	2657	.999232	.865335
	44	2538	.999232	.896352
S-Unstaged	50	2400	.999258	.951461
	70	2750	.999316	.992439

POWER GENERATION SYSTEM
MISSION "C" WITH 30 HR. MAX. HOLD

TABLE V 11

Package	Config. No.	Unit	No. Req'd	CONFIGURATION Dimensions	Volume " Unit	Volume " Total	Weight # Unit	Weight # Total
ECP	IV 50% Redundacy	Module	3 Per Batt.	12.5 dia. x 18.7 Long. GE Fig - Module as Mounted	2295.0 (3406.0)	6885.0 (10218.0)	53.0	159.0
		Control Unit	1 Per Batt.	10.0 x 8.5 x 2.88 High	244.8	244.8	11.7	11.7
		Total Battery				7129.8 (10462.8)		170.7
FSSP	Unstaged Mounted in Ascent Stage	Oxygen Vessel (1-11)	1	15.60 Sphere Dia.	1987.8	1987.8		20.60
		Usable Fluid						49.36
		Hydrogen Vessel (1-11)	1	20.50 Sphere Dia.	4510.9	4510.9		20.48
		Fluid						6.17
		Oxygen Vessel (8-11)	1	11.87 Sphere Dia.	875.7	875.7		12.84
		Fluid						18.06
		Hydrogen Vessel (8-11)	1	17.50 Sphere Dia.	2806.2	2806.2		16.83
		Fluid						2.26

PRATT & WHITNEY

POWER GENERATION SYSTEM
MISSION "C" WITH 30 HOUR MAXIMUM HOLD

Table 12

Package	Config. No.	Unit	No. Reqd.	Dimensions - In.	Volume In.^{3} Unit	Volume In.^{3} Total	Weight # Unit	Weight # Total
		C O N F I G U R A T I O N						
E C P	IV 50% REDUNDANCY	Module	3	14.0 dia. x 32 long	4,926	14,778	47.62	142.86
		Inert Gas System		Container 6" sphere dia. Valve 5" dia. x 7 long Valve $3\frac{1}{2}$ x 3 x $1\frac{1}{2}$ x 2	Included in module volume		9.70	29.10
		Peak Load Battery	1	8.57 x 4.5 x 4.5 deep	174	174	12.00	12.00
		Elect. Connections	1				3.00	3.00
		Controls	1					16.20
		Instrumentation	1					4.60
F S S P	UNSTAGED MOUNTED IN ASCENT STAGE	Hydrogen Vessel (1-11) Usable Fluid	1	29.6 sphere dia.	13,579	13,579	30.10	30.10
		Oxygen Vessel (1-11) Fluid	1	14.2 sphere dia.	1,499	1,499	10.30	10.30
		Hydrogen Vessel (8-11) Fluid	1	23.6 sphere dia.	6,882	6,882	13.00	13.00
								10.30
		Oxygen Vessel (8-11) Fluid	1	10.4 sphere dia.	589	589	4.80	4.80
								16.00
		Hydrogen Tank Components						13.26
		Oxygen Tank Components						13.26

SUNDSTRAND AVIATION

TABLE V13

POWER GENERATION SYSTEM
MISSION "C" 30 HOUR MAXIMUM HOLD

PACK-AGE	CONFIG. NO.	UNIT	DIMENSIONS "	NO. PER CONFIG.	VOLUME 11^3 UNIT	VOLUME 11^3 TOTAL	WEIGHTS #s UNIT	WEIGHTS #s TOTAL	POWER	REDUNDANCY %	ALTERNATE WEIGHTS #s UNIT	ALTERNATE WEIGHTS #s TOTAL	POWER	REDUNDANCY %
ECP	2	Reaction Chamber	1.5 Dia. x 5.5 Heigth	2	9.75	19.50	4.50	9.00	ALL DC	100	4.50	9.0	ALL DC	100
		Expander/Compresser Eng.	11.375 x 9.5 x 24.75	2	2592.00	5184.00	25.60	51.20			25.60	51.20		
		Controls	4.5 x 4.0 x 5.0	2	90.00	180.00	5.50	11.00			5.50	11.00		
		Generator & Elect. Syst.	5.0 x 9.5 Dia. Included within Expander/Compress Engine Dimen.	2			32.00	64.00			30.70	61.40		
		Control Syst.Cables		2			2.00	4.00			2.00	4.00		
		Heat Exchangers	6.0 x 2.0 x 24.0	2	188.00	376.00	10.00	20.00			10.00	20.00		
		Pre/Re/Afterheater	3.5 Dia. x 10.5	2	93.00	186.00	3.28	6.56			3.28	6.56		
						5945.50		165.76				163.16		
	3	Reaction Chamber	1.5 Dia. x 5.5 Heigth	3	9.75	29.25	4.50	13.50	ALL DC	200	4.50	13.50	ALL DC	200
		Expander/Compresser Eng.	11.375 x 9.5 x 24.75	3	2592.00	7776.00	25.60	76.80			25.60	76.80		
		Controls	4.5 x 4.0 x 5.0	3	90.00	270.00	5.50	16.50			5.50	16.50		
		Generator & Elect. Syst.	5.0 x 9.5 Dia. Included With Expander/Compress Engine Dimen.	3			32.00	96.00			30.70	91.40		
		Control Syst. Cables		3			2.00	6.00			2.00	6.00		
		Heat Exchangers	6.0 x 2.0 x 24.0	3	188.00	564.00	10.00	30.00			10.00	30.00		
		Pre/Re/Afterheater	3.5 Dia. x 10.5	3	93.00	279.00	3.28	9.84			3.28	9.84		
						8918.25		248.64				244.04		
UNMANNED ASCENT		Hydrogen Vessel (1-11)	44.0 Sphere Dia.	1	44582.00	44582.00		131.00						
		Total Fluid						114.10						
		Oxygen Vessel (1-11)	10.3 Sphere Dia.	1	570.00	570.00		13.20						
		Fluid						8.30						
		Hydrogen Vessel (1-11)	29.5 Sphere Dia.	1	13271.00	13271.00		63.00						
		Fluid						39.10						
		Oxygen Vessel (1-11)	5.0 Sphere Dia.	1	69.00	69.00		1.40						
		Fluid						1.00						
		Cryogenic Valve Module						17.20						

GENERAL ELECTRIC "ECP"

POWER GENERATION SYSTEM
ENERGY CONVERSION PACKAGE

TABLE V 14

No.	Redundancy %	CONFIGURATION Details: Unit	No. Req'd	Included In	Dimensions "	Volume "	Weight #	Features
		Cells	36	Per Stack	Active Area 54sq."	-		1. Utilizes Existing Gemini Cell Size.
		Stacks	3	Per Section				
		Sections	2	Per Battery	12.5 dia.x25.0 Long.	4586" (As Mounted)	72.0	
I	100	Control Unit	1	Per Battery	6.5"x12.3"x2.88 High	230.3"	10.7	2. Requires Voltage Regulator
		Total Fuel Batt.				6394	155.0	
		Cells	34	Per Stack	Active Area 54sq."			1. Gemini Cell Size Utilized but Optimized for Power, Range, and Inherent Voltage Regulation
		Stacks	2	Per Section				
		Sections	3	Per Battery	12.5 dia.x18.7 Long.	3406" (As Mounted)	53.0	
IV	50	Control Unit	1	Per Battery	10.0"x8.5"x2.88 High	244.8"	11.7	
		Total Fuel Batt.				7085	170.0	
		Cells	36	Per Stack	Active Area 54sq."			1. Utilizes Existing Gemini Cell Size
		Stacks	3	Per Section				
		Sections	3	Per Battery	12.5 dia.x25.0 Long.	4586" (As Mounted)	72.0	
V	200	Control Unit	1	Per Battery	12.3"x6.5"x2.88 High	230.3"	10.7	2. Requires Voltage Regulator
		Total Fuel Batt.				9504	227.0	

POWER GENERATION SYSTEM

FLUID STORAGE AND SUPPLY PACKAGE

TABLE V15

BASES: 30 HOUR MAXIMUM HOLD MISSION "C"

MISSION MODE	FUEL BATTERY CONFIGURATION	FLUID AND MISSION MODE PHASE	FLUID VESSEL SYSTEM SERIAL NO.	VESSEL DIMENSIONS		SYST. WEIGHT-INCLUD. COMPONENTS		SYSTEM PERFORMANCE			
								FLOW RATE		HEATER	
				O.D.-INCHES	VOLUME #	FILLED WITH FLUID	USABLE FLUID	MAX.	MIN.	WATTS	KWH
ASCENT	I	Oxygen (1-11)	CAO-1	15.80	2065.2	72.26	51.34	1.58	.146	30	1.05
		Oxygen (8-11)	CAO-5	12.10	927.6	32.63	19.46	1.56	.336	30	.4
		Hydrogen (1-11)	CAH-1	20.95	4814.5	27.85	6.417	.198	.0183	10	.242
		Hydrogen (8-11)	CAH-5	17.70	2003.5	19.48	2.433	.193	.042	10	..141
	II	Oxygen (1-11)	CAO-2	15.40	1912.3	66.92	47.02	1.41	.140	30	.96
		Oxygen (8-11)	CAO-6	11.87	875.0	30.81	17.97	1.38	.288	30	.368
		Hydrogen (1-11)	CAH-2	20.00	4188.8	25.48	5.877	..176	.017	10	.220
		Hydrogen (8-11)	CAH-6	17.50	2806.2	19.08	2.246	.173	.036	10	.133
	III	Oxygen (1-11)	CAO-3	15.40	1912.3	67.84	47.60	1.41	.134	30	.98
		Oxygen (8-11)	CAO-7	11.98	900.3	31.92	18.72	1.39	.288	30	.383
		Hydrogen (1-11)	CAH-3	20.15	4283.7	25.70	5.95	.176	.0168	10	.223
		Hydrogen (8-11)	CAH-7	17.60	2854.6	19.27	2.34	.174	.036	10	.137
	IV	Oxygen (1-11)	CAO-4	15.60	1987.8	69.96	49.36	1.50	.148	30	1.01
		Oxygen (8-11)	CAO-8	11.87	875.7	30.90	18.06	1.47	.304	30	.37
		Hydrogen (1-11)	CAH-4	20.50	4510.9	26.65	6.17	.1855	.0185	10	.232
		Hydrogen (8-11)	CAH-8	17.50	2806.2	19.09	2.257	.184	.038	10	.133

GENERAL ELECTRIC
"FSSP"

TABLE V16

POWER GENERATION SYSTEM
FLUID STORAGE & SUPPLY PACKAGE

BASES: 30 HR. MAX. HOLD MISSION "C"

MISSION MODE	FUEL BATTERY CONFIGURATION	FLUID AND MISSION MODE PHASE	FLUID VESSEL SYSTEM SERIAL NO.	VESSEL DIMENSIONS O.D.-INCHES	VESSEL DIMENSIONS VOLUME "3	SYST. WEIGHT-INCLUD. COMPONENTS FILLED WITH FLUID	SYST. WEIGHT-INCLUD. COMPONENTS USABLE FLUID	SYST. PERFORMANCE FLOW RATE MAX	SYST. PERFORMANCE FLOW RATE MIN	HEATER WATTS	HEATER KWH
DESCENT	I	Oxygen (1-8)	CDO-1	14.10	1468.0	51.70	34.80	1.58	.146	30	.71
		Oxygen (50% 1-8)	CDO-5	11.75	749.4	30.03	17.40	1.58	.146	30	.356
		Hydrogen (1-8)	CDH-1	17.70	2923.5	20.35	4.35	.198	.0183	10	.156
		Hydrogen (50% 1-8)	CDH-5	17.40	2788.3	18.87	2.175	.198	.0183	10	.1295
	II	Oxygen (1-8)	CDO-2	13.70	1346.4	47.63	31.60	1.41	.136	30	.645
		Oxygen (50% 1-8)	CDO-6	11.47	690.1	28.05	15.80	1.41	.136	30	.325
		Hydrogen (1-8)	CDH-2	17.20	2644.3	19.43	3.95	.176	.017	10	.140
		Hydrogen (50% 1-8)	CDH-6	17.20	2644.3	18.43	1.975	.176	.017	10	.122
	III	Oxygen (1-8)	CDO-3	13.80	1376.1	48.44	32.10	1.41	.134	30	.658
		Oxygen (50% 1-8)	CDO-7	11.50	706.33	28.34	16.05	1.41	.134	30	.33
		Hydrogen (1-8)	CDH-3	17.27	2656.9	19.58	4.01	.176	.0168	10	.142
		Hydrogen (50% 1-8)	CDH-7	17.15	2611.1	18.41	2.005	.176	.0168	10	.123
	IV	Oxygen (1-8)	CDO-4	13.90	1426.2	49.99	33.30	1.48	.148	30	.685
		Oxygen (50% 1-8)	CDO-8	11.55	696.7	29.13	16.65	1.48	.148	30	.342
		Hydrogen (1-8)	CDH-4	17.55	2830.3	20.15	4.165	.1855	.0185	10	.147
		Hydrogen (50% 1-8)	CDH-8	17.30	2711.1	18.66	2.083	.1855	.0185	10	.126

Pratt & Whitney
"ECP"

POWER GENERATION SYSTEM
Energy Conversion Package

TABLE V 17

BASES: APOLLO STRUCTURE AND ADVANCED PERFORMANCE - 30 HR MAX. HOLD MISSION "C"

CONFIGURATION

NO.	REDUNDANCY	UNIT	NO REQ'D	INCLUDED IN	DIMENSIONS"	VOLUME"	WEIGHT#
1	100%	Fuel Cell Assembly	2		14.5 Dia x 32 Long.	5284	@73.24 =146.48
		Battery Connect	1		Batt. 8.57x4.5x4.5 Deep	174	14.00
		Controls	1				16.20
		Inert Gas System	1	Fuel Cell Cannaster	Container 6" Sphere Dia. Valve 5" Dia x 7 Long. Valve 3"x1½"x3½"x2	113 687 32	9.70
		Instrumentation	1				4.60
2	50%	Fuel Cell Assembly	3		14.0 Dia x 32 Long.	4926	@47.62 =142.86
		Battery-Connect	1		Batt. 8.57x4.5x4.5 Deep	174	15.00
		Controls					16.20
		Inert Gas System		Fuel Cell Cannaster	Container 6" Sphere Dia. Valve 5" Dia x 7 Long. Valve 3"x1½"x3½"x2	113 687 32	9.70
		Instrumentation					4.60
3	100%	Fuel Cell Assembly	2		14.5 Dia x 32 Long.	5284	@73.24 =146.48
		Battery-Connect	1		Batt. 8.57x4.5x4.5 Deep	174	14.00
		Controls					16.20
		Inert Gas System		Fuel Cell Cannaster	Container 6" Sphere Dia. Valve 5" Dia x 7 Long. Valve 3"x1½"x3½"x2	113 687 32	9.70
		Instrumentation					4.60
4	50%	Fuel Cell Assembly	3		14.0 Dia x 32 Long.	4926	@47.62 =142.86
		Battery-Connect	1		Batt. 8.57x4.5x4.5 Deep	174	15.00
		Controls					16.20
		Inert Gas System		Fuel Cell Cannaster	Container 6" Sphere Dia. Valve 5: Dia x 7 Long. Valve 3"x1½"x3½"x2	113 687 32	9.70
		Instrumentation					4.60

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PRATT & WHITNEY
"PSSF"

POWER GENERATION SYSTEM
FLUID STORAGE & SUPPLY PACKAGE

TABLE V 18

BASIS: "APOLLO STRUCTURE AND ADVANCED PERFORMANCE - 30 MM MAX HOLD. MISSION "C"

MISSION MODE	FUEL BATTERY CONFIGURATION	FLUID AND MISSION MODE PHASE	TANK COMPONENTS DIA."	DIMENSIONS "	VOLUME CU"	WEIGHT EMPTY	WEIGHT-FLUID	WEIGHT-TOTAL
DESCENT STAGE	No 1	Hydrogen 1-8	26.4	Spherm	963⅓	18.00	16.00	
	No 2		25.6	Sphere	878⅓	16.50	14.50	
	No 1	Hydrogen 50% 1-8	21.8	Sphere	542⅝	11.10	8.00	
	No 2		21.2	Sphere	498⅝	10.50	7.30	
	No 1	Oxygen 1-8	12.6	Sphere	104⅞	7.50	30.70	
	No 2		13.0	Sphere	115⅜	8.00	33.40	
	No 1	Oxygen 50% 1-8	11.2	Sphere	73⅝	3.60	10.40	
	No 2		10.6	Sphere	62⅝	4.90	16.70	
	Nos 1 & 2	Hydrogen Tank Components						13.26 13.26
	Nos 1 & 2	Oxygen Tank Components						13.26 13.26
ASCENT STAGE	No 3	Hydrogen 1-11	30.0	Sphere	14137.	24.20	24.00	
	No 4		29.6	Sphere	13579.	23.60	23.40	
	No 3	Hydrogen 8-11	23.6	Sphere	6882.	13.20	10.60	
	No 4		23.6	Sphere	6882.	13.00	10.30	
	No 3	Oxygen 1-11	13.8	Sphere	1376.	9.90	44.20	
	No 4		14.2	Sphere	1499.	10.30	46.60	
	No 3	Oxygen 8-11	10.4	Sphere	589.	4.70	15.60	
	No 4		10.4	Sphere	589.	4.80	16.00	
	Nos 3 & 4	Hydrogen Tank Components						13.26 13.26
	Nos 3 & 4	Oxygen Tank Components						13.26 13.26

ALLIS-CHALMERS
"ECP"

TABLE V 19

POWER GENERATION SYSTEM
Energy Conversion Package

CONFIGURATION
DETAILS

NO.	REDUNDANCY %	UNIT	NO. REQ'D	INCLUDED IN	DIMENSION "	VOLUME	WEIGHT # EACH UNIT
I	100%	Fuel Cell Module	2	System			66.0
		Canister	2	Module	8.5 Dia. x 21 Long		5.0
		Electric Controls	2				1.0
		Solenoid Valves	2				1.5
		Isolation Valves	2				1.5
		Relief Valves	2				1.0
		Pressure Regulator	2				2.0
		Electric Bus	2				2.0
		Switches	2				3.0
		Coolant Mixing Valve	2				1.0
		Miscellaneous	2				2.0
		Coolant in Canister	as req'd	Module			4.0
		Single Module					90.0
		Vacuum Flask	1				2.0
		Canister Isolation Controller	1				3.0
		O_2 Purge Controller	1				2.0
		AG ZN Batteries	2				5.0
		Total Components					17.0
		TOTAL SYSTEM					197.0
II	50%	Fuel Cell Module	3	System			31.0
		Canister	3	Module	6.5 Dia. x 21 Long		4.0
		Electric Controls					1.0
		Solenoid Valves					1.5
		Isolation Valves					1.5
		Relief Valves					1.0
		Pressure Regulators					2.0
		Electric Bus					2.0
		Switches					3.0
		Coolant Mixing Valve					1.0
		Miscellaneous					2.0
		Coolant in Canister	as req'd	Module			2.0
		Single Module					
		Exterior System Components	As above				17.0
		TOTAL SYSTEM					188.0
III	200%	TOTAL SYSTEM		3 Fuel Cell Modules	8.5 Dia. x 21 Long		287.0

ALLIS-CHALMERS
"FSSP"

POWER GENERATION SYSTEM
FLUID STORAGE AND SUPPLY PACKAGE

TABLE V 20

BASES: MISSION "C"

	FLUID AND MISSION MODE PHASE	TANK AND COMPONENTS DIA."	DIMENSIONS"	VOLUME CU"	WEIGHT-EMPTY	WEIGHT-FLUID	WEIGHT-TOTAL
	Hydrogen 1-8	16.6	Sphere	2395.	3.77	4.12	7.89
	Hydrogen 50% 1-8	15.7	Sphere	2026.	5.39	2.06	7.45
	Oxygen 1-8	13.1	Sphere	1170	2.58	32.95	35.53
	Oxygen 50% 1-8	12.1	Sphere	928.	1.54	16.50	18.04
	Flow Control Components						10.00
	TOTAL						78.91
	Hydrogen 1-11	19.1	Sphere	3648	5.28	6.17	11.45
	Hydrogen 8-11	14.9	Sphere	1732	4.63	2.38	7.01
	Oxygen 1-11	15.0	Sphere	1767	3.56	49.35	52.91
	Oxygen 8-11	12.7	Sphere	1073	1.87	19.03	20.90
	Flow Control Components						10.00
	TOTAL						102.27

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Sundstrand "ECP"

POWER GENERATION SYSTEM
ENERGY CONVERSION PACKAGE

TABLE V 21

Type Of Power	No.	Item	POWER UNIT Length	Width	Size Height	Volume	Weight	No. Per Unit	Total Weight	Total Volume	Redundancy %
ALL DC	2	Reaction Chamber	-	1.5 Dia.	5.5	9.75 (1)	4.5	2	9.0	(1) 19.5	100
		Expander/Compress.	11,375	9.5	24.75	2592.0	25.6	2	51.2	5184.0	
		Controls	4.5	4.0	5.0	90.0	5.5	2	11.0	180.0	
		Generator -	5.0	9.5 Dia.	-	355.0 (1)				-	
		& Elect. System	-	-	-	-	32.0	2	64.0	-	
		Control Syst. Cables	-	-	-	-	2.0	2	4.0	-	
		Heat Exchangers	6.0	2.0	24.0	188.0	10.0	2	20.0	376.0	
		Pre/Re/After Heater	10.5	3.5 Dia.	-	93.0	3.28	2	6.56	186.0	
									165.76	5945.5	
	3	Reaction Chamber	-	1.5 Dia.	5.5	9.75 (1)	4.5	3	13.50	(1) 29.25	200
		Expander/Compresser	11,375	9.5	24.75	2592.0	25.6	3	76.80	7776.00	
		Controls	4.5	4.0	5.0	90.0	5.5	3	16.50	270.00	
		Generator -	5.0	9.5 Dia.	-	355.0				-	
		& Elect. System	-	-	-	-	32.0	3	96.00	-	
		Control Syst. Cables	-	-	-	-	2.0	3	6.00	-	
		Heat Exchangers	6.0	2.0	24.0	188.0	10.0	3	30.00	564.00	
		Pre/Re/After Heater	10.5	3.5 Dia.	-	93.0	3.28	3	9.84	279.00	
									248.64	8918.25	
AC-DC	2	Reaction Chamber	-	1.5 Dia.	5.5	9.75 (1)	4.50	2	9.00	(1) 19.5	100
		Expander/Compresser	11,375	9.5	24.75	2592.0	25.60	2	51.20	5184.0	
		Controls	4.5	4.0	5.0	90.0 (1)	5.50	2	11.00	180.0	
		Generator -	5.0	9.5 Dia.	-	355.0				-	
		& Elect. System	-	-	-	-	30.70	2	61.40	-	
		Control Syst. Cables	-	-	-	-	2.00	2	4.00	-	
		Heat Exchangers	6.0	2.0	24.0	188.0	10.00	2	20.00	376.0	
		Pre/Re/After Heater	10.5	3.5 Dia.	-	93.0	3.28	2	6.56	186.0	
									163.16	5945.5	
	3	Reaction Chamber	-	1.5 Dia.	5.5	9.75 (1)	4.50	3	13.50	(1) 29.25	200
		Expander/Compresser	11,375	9.5	24.75	2592.0	25.60	3	76.80	7776.00	
		Controls	4.5	4.0	5.0	90.0 (1)	5.50	3	16.50	270.00	
		Generator -	5.0	9.5 Dia.	-	355.0				-	
		& Elect. System	-	-	-	-	30.70	3	91.40	-	
		Control Syst. Cables	-	-	-	-	2.00	3	6.00	-	
		Heat Exchangers	6.0	2.0	24.0	188.0	10.00	3	30.00	564.00	
		Pre/Re/After Heater	10.5	3.5 Dia.	-	93.0	3.28	3	9.84	279.00	
									244.04	8918.25	

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SECTION VI - EMERGENCY CONSIDERATIONS FOR LEM ELECTRICAL POWER SUBSYSTEM

Introduction

This section establishes a rational approach for design criteria effecting the electrical power subsystem.. The assumptions made herein and in Section II form the basis for configuration studies and will be utilized until experience indicates modification. In particular, this section attempts to establish the LEM power and energy requirements, for normal and emergency conditions, regardless of the power source.

Determination of General Types of Emergencies

Section II "Load Analysis" indicated LEM power requirements for each of three missions, A, B, and C. Mission "C" resulted in the highest requirement and at this time appears to represent the best overall profile. Accordingly, power requirements contained herein are based on Mission "C" as presented in Section II. Mission "C", while considering some contingency operating modes, is basically a conservative approach. This section will attempt to determine what constitutes an emergency and what affect the assumptions made have on the power requirements for the LEM.

Just what constitutes an emergency, and what provisions should be made to cover them, is an area of consideration where there are many approaches. As initial guidelines, the following paragraphs are drawn from Exhibit "B" of the LEM Work Statement dated 20 December 1962:

2.1.2.3.4 - Abort Initiation. - Provisions shall be made inccrew initiation of all abort modes. Initiation of abort modes by ground command or automatic systems shall be provided when this enhances crew safety.

2.1.2.5 (Partial) - Earth Landing. - The spacecraft shall have the capability of initiating a return and earth landing maneuver at any time during either lunar or orbital missions.

2.1.3.2.2 - Emergency - The probability that none of the crewmen shall have been subjected to conditions greater than the emergency limits specified in the crew requirements section (Para. 2.4.2) shall be 0.999. Of this overall crew safety goal, the crew safety goal apportioned to the LEM shall be 0.9995.

2.2.3.1 - Multiple Failure - The decision to design for single or multiple failures shall be based on the expected frequency of occurrence as it affects system reliability and safety.

2.2.3.2 - Fail Safe - System or component failure shall not propagate sequentially, i.e., design shall "fail safe".

2.2.3.3. - Design Margins - All spacecraft systems shall be designed to positive margins of safety.

2.4.2 - Emergency Limits - Emergency limits are defined as the environmental limits beyond which there is a high probability of permanent injury, death, or incapacity to such extent that the crew could not perform well enough to survive.

There are other paragraphs which could be referenced, but the above represents the most significant guidelines for handline emergency situations. For purposes of defining the general kinds of emergencies, the following is established:

Vehicle Emergency - That event which results in structural damage, injection into wrong orbit, mission abort, etc. or major threat to crew safety. A vehicle emergency can arise out of any subsystem malfunction or failure that leads to one of the above situations.

Electrical Power Subsystem (EPS) Emergency - That situation where a failure or condition arises, such failure or condition being traceable to the electrical power subsystem. For this situation two types of emergencies are defined.

1. Type 1 - Any EPS event which threatens crew survival or requires mission abort.

2. Type 2 - Any EPS event that requires crew action or requires a change in mission profile subsequent to lunar landing. (By definition - an abort cannot occur once the LEM lands on the moon. There can only be a change in mission profile from that point on.) The design of the EPS will be such that operating under the above emergencies, the intent of the referenced Work Statement paragraphs will be met.

Application of Criteria Established to Electrical Load Profile "C"

Load profile "C" resulted in the following electrical power requirements:

MISSION "C"

PHASE	OPERATION	TIME (HRS)	KW HRS	
1	Translunar	65.3	12.1	12.1 KW HRS
2	Pre-Separation Checkout	2.5	2.47	
3	Lunar Orbit	2.1	3.13	
4	Descent	0.5	0.86	29.46KW HRS
5	Terminal Descent	0.1	0.17	
6	Post-Landing Checkout	2.3	2.26	
7	Lunar Stay	21.9	17.3	
8	Post-Launch Checkout	3.1	3.27	
9	Ascent & Rendezvous	1.5	2.56	
10	Rendezvous Contingency	16.5	17.0	19.76KW HRS
11	Crew Transfer	0.5	0.2	
TOTALS		116.3	61.3	

It is recognized that the time involved for the various phase operations will change as will the energy required. However, any discussion of the subject of this memo must revolve around a particular mission profile as indicated above. It is noted that the above energy requirements do not include provisions for reserve and growth. This will be the subject of another discussion.

The above requirements can be summarized as follows:

Translunar (Phase 1)	- 12.1 KW HRS.
Descent, Lunar Stay (Phases 2-8)	- 29.5 KW HRS.
Ascent and Rendezvous (Phases 9-11)	- 19.8 KW HRS.

Before determining the effect of vehicle emergencies on the above requirements, there are other conditions related to the Apollo in general which affect the design of the electrical power subsystem.

Condition 1 - The Work Statement notwithstanding, the possibility exists of obtaining LEM translunar power requirements (presently estimated at 12.1 KW HRS.) from the CSM. If it is assumed that power will be available from the CSM in the amounts required (initial indications appear positive), the LEM power subsystem need be sized for 49.2 KW HRS. instead of 61.3 KW HRS. The affect of this approach on the weight and reliability (the amount of operating time would be reduced) of the LEM EPS is significant. The umbilical connection required for this operation is not considered an argument against such an arrangement since present indications are that an umbilical will be required regardless of whether the CSM supplies power to the LEM. The subsystem configuration study presently underway is considering both approaches, i.e., with and without power from the CSM.

Condition 2 - This condition relates to the flight time capabilities of the LEM and the CSM. Paragraph 2.1.2.4.1 of the referenced Work Statement indicates that the LEM systems shall be capable of a two day mission without resupply, while the CSM systems shall be capable of a 14 day mission without resupply. For Lunar Landing Missions, 7 of the 14 CSM days may be in lunar orbit. The question that arises is whether the LEM will be required to orbit the moon for seven days with the CSM before it actually performs its two day mission. If this is so, and power is not available from the CSM, the LEM power subsystem would then be required to provide whatever power would be required during this seven day period, (this would be in addition to the 61.3 KW HR.) or if power is available from the CSM, the CSM would have to supply this power. This later case would require longer standby times for reactant storages that could form part of the EPS.

The foregoing possibility is not being considered at this time.

Vehicle Emergencies as Related to Load Profile "C"

The most significant vehicle emergency arises from the case where the first attempt at rendezvous is not successful and a second attempt is required. This situation gives rise to a requirement for the LEM to orbit the moon awaiting a second attempt. The preliminary load analysis (Mission"C") allowed 16.5 hours for this "contingency" and indicated an average power level of 1030 watts made up as follows:

Communications	105 watts
Instrumentation	23 watts
Nav. & Guid.	186 watts
Stab. & Cont.	250 watts
Displays	64 watts
Environmental Cont.	274 watts
Crew Systems	33 watts
Electrical Power	68 watts
Propulsion	10 watts
Reaction Control	17 watts
	1030 watts X 16.5 Hrs. = 17 KW HRS.

It now appears that the above requirement is conservative and that substantial savings could be made by taking a hard, but realistic, look at minimizing the requirements during the rendezvous contingency phase.

Communications: The communication subsystem presently consists of:

1.	UHF Transponder	- 14 watts
2.	UHF Power Amplifier	- 65 watts (50 watts receive)
3.	UHF Antenna Servo	- 35 watts
4.	VHF Transceiver	- 64 watts
5.	Intercom	- 6 watts
6.	Television	- 20 watts

To arrive at the average power level during rendezvous contingency, the following assumptions are made:

(a) Item 1 will be on full time for an average of 14 watts.
(b) Item 2 will have a full time standby level of 7 watts plus a duty cycle as follows:

Since the LEM is behind the moon for periods of time, full time communications with the earth will not be possible. Communications will be possible for roughly 60% of the contingency time. During this 60% time period, it is assumed that the LEM transmits 1/3 of the time and receives 2/3 of the time. The average power for this item during rendezvous contingency figures out to 36 watts.

(c) Item 3 will have the same duty cycle as Item 2 and its average power is figured at 22 watts.

(d) Item 4 will have a full time standby level of 28 watts. Assuming a 50,000 foot LEM orbiting altitude and a 100 N.M. CSM orbiting altitude during rendezvous contingency, line of site communications between the two spacecraft will be possible for roughly 3 hours (Ref. - K. Speiser Memo PDM-323A-91) the average power is therefore 35 watts.

(e) Item 5 is assumed to be on full time for an average power of 6 watts.

(f) Item 6 will not be used during rendezvous contingency.

The average communications power for rendezvous contingency is therefore 99 watts.

Instrumentation: The instrumentation subsystem presently consists of:

1.	PCM Telemetry	- 18 watts
2.	Clock	- 11 watts
3.	In-Flight Test System	- 37 watts
4.	Recorder	- 15 watts
5.	Sensors	- 50 watts
6.	Scientific Instrumentation	2400 watt-hours (moon operation)

To arrive at the average power level during rendezvous contingency, the following assumptions are made:

(a) Items 1 and 5 will have a 30% duty cycle for an average power of 18 watts.

(b) Item 2 will have a 100% duty cycle for an average of 11 watts.

(c) The average power involved with the operation of the IFTS is negligible.

(d) Item 4 will have a 15% duty cycle for an average power of 3 watts.

The average instrumentation power for rendezvous contingency is therefore 32 watts.

Navigation and Guidance: The N & G system presently consists of:

1.	Inertial Meas. Unit	- 100 watts
2.	Optical Meas. Unit	- 2 watts
3.	CDU Coupling & Display Unit	- 8 watts
4.	Computer	- 80 watts
5.	Power & Servo Assembly	- 20 watts
6.	IMU Coupling & Display Unit	- 12 watts
7.	Displays & Controls	- 10 watts
8.	Radar Altimeter	- 15 watts
9.	Rendezvous/S. R. Radar	- 60 watts

To arrive at the average power level during rendezvous contingency, the following assumptions are made:

(a) Item 1 will be on full time for an average of 100 watts.

(b) Item 2 will be on full time for an average of 2 watts.

(c) Item 3 will be on full time for an average of 8 watts.

(d) Item 4 will have a full time standby level of 20 watts plus a duty cycle as follows: once each hour the computer will be operated for 12 minutes. The average power for this item is then 32 watts.

(e) Items 5, 6, and 7 will be on full time for an average of 42 watts.

(f) Items 8 and 9 will not be on.

The average N.& G power for rendezvous contingency is therefore 164 watts.

Stabilization and Control: The S & C system presently consists of:

1.	Strap-Down Altitude Ref.	- 100
2.	Guidance Coupler Unit	- 40
3.	Altitude & Translation C.U.	- 30
4.	Descent Abort Programmer	- 35
5.	Back-Up Ascent Programmer	- 5

6.	Gyro Rate Sensor (3 Axis)	- 65
7.	Comparator in-flight test system	- 10

To arrive at the average power level during rendezvous contingency, the following assumptions are made:

(a) Item 1 will be on full time for an average of 100 watts.

(b) Item 2 is assumed to have a full time standby level of 10 watts. Since S & C should not be a constantly critical requirement for a rendezvous contingency, it is expected that manual corrections can be made for most of the contingency time. To this end item 2 is assumed to be required for full operation 10% each orbit. The average power for this item is 13 watts.

(c) Because of the nature of the operation described in Item 2 above, Items 3, 4, 5, and 6 are assumed to be turned off.

(d) Item 7 is assumed to have a duty cycle of less than 10 percent in which case the power required is negligible.

The average S & C power for rendezvous contingency is therefore 113 watts.

Displays: The displays presently consist of:

1.	R & R Indicator	- 56 watts
2.	H & H Indicator	- 56 watts
3.	S & C Indicator	- 8 watts
4.	Misc. Indicator Lights	- 45 watts
5.	Lighting Displays	- 45 watts

To arrive at the average power level during rendezvous contingency, the following assumptions are made:

(a) Items 1 and 2 will not be on.

(b) Item 4 will be such that its duty cycle will be 10% making its average power 5 watts.

(c) Items 3 and 5 will be on full time for an average power of 53 watts.

The average display power for rendezvous contingency is therefore 58 watts.

Environmental Control: This system presently consists of:

1.	Suit Compressor	- 101 watts
2.	Glycol Pump	- 24 watts
3.	Cabin Fan	- 41 watts
4.	Six Heater	- 86 watts (left on moon)
5.	Controls (Temp.)	- 10 watts
6.	Cat. Burn and Display	- 12 watts
7.	Back-Pack Recharge	- 100 watts (moon operation)

(a) Items 1, 2, 3, 5 and 6 are on full time for an average power of 188 watts.

The average ECS power for rendezvous contingency is therefore 188 watts.

Crew Systems: This system presently consists of:

1.	Suit Biological Sensor	5 watts
2.	Exterior Postion and Signal Lights	120 watts
3.	Interior Area Lights	50 watts
4.	Landing Lights	200 watts (left on moon)

To arrive at the average power level during rendezvous contingency, the following assumptions are made:

(a) Item 1 will be on full time for an average power of 5 watts.

(b) Item 2 will not be on.

(c) Item 3 will be used as required for an average of 25 watts.

The average crew systems power for rendezvous contingency is therefore 30 watts

Electrical Power - Inasmuch as this system is presently undefined, it is estimated that the power source and distribution system will require an average control power of 70 watts.

Propulsion - The average power for this system has been previously figured at 10 watts. At present this number will be retained as is.

Reaction Control - The average power for this system has been previously figured at 17 watts. At present this number will be retained as is.

As a result of the foregoing analysis the total average power for the rendezvous contingency is now:

Communications	99 watts
Instrumentation	32 watts
Nav. & Guidance	164 watts
Stab. & Cont.	113 watts
Displays	58 watts
Environmental Control	188 watts
Crew Systems	30 watts
Electrical Power	70 watts
Propulsion	10 watts
Reaction Control	17 watts
TOTAL	781 watts average (16.5 x 781 = 12.9 KW HRS.)

In accordance with load profile "C" the new requirement for Ascent and Rendezvous (Phases 9, 10 and 11) is now 15.7 KW HRS. as apprised to the previously arrived at 19.8 KW HRS.

Application of Criteria Established to Emergencies Associated with the Electrical Power Subsystem

Part I indicated the type of emergencies associated with the EPS. Given a subsystem configuration, the type of failures that could cause such emergencies are:

1. Partial or complete failure of the main power source(s).
2. Partial or complete failure of inversion or conversion equipment.
3. Partial or complete failure of the power distribution or control equipment.

To establish an emergency load requirement, it is necessary to establish at what point in the LEM mission a given EPS emergency will occur and then determine what equipments need be used to successfully recover. Without establishing the conditions of emergency and the length of time involved, meaningful provisions cannot be made.

To establish emergency load requirements the following situations are postulated.

Approach 1:

Here it is assumed that to meet a given reliability the main power source consists of two totally redundant sources, each source capable of delivering the total normal demand. This being so, the failure of one power source does not necessarily mean that electrical loads need be shut down inasmuch as the remaining power source is capable of supplying the total demand. It is assumed that if cryogenics are associated with the power source, they would be redundant. This line of reasoning leads to the conclusion that in a singularly redundant system, the loss of the first power source does not necessarily threaten mission completion or crew survival. Therefore, the establishment of an emergency load is not required for this case.

Approach 2:

In this approach it is assumed that to meet a given reliability the main power source consists of three power sources. However, to save weight each of the power sources is capable of supplying 50% of the normal load. Stated another way, any two of the three sources is required to supply the total normal demand. (This situation is similar to the CSM arrangement). In this arrangement the failure of one of the power sources has no affect on normal operation. The failure of the second source requires that loads be monitored to remain within the capability of the remaining 50% source. This is an emergency condition. To obtain design parameters it is now necessary to stipulate when in the mission this emergency occurs. To meet the intent of the Work Statement it is necessary to assume the worst case. At this point, the worst case appears to be that this emergency occurs during descent. This requires that emergency provisions must cover the possibility of a rendezvous contingency similar to Phase 10 previously described. In this situation, electrical loads must be restricted to those equipments necessary to assure crew safety. The following equipments are those assumed to be required for this condition:

Communications

1.	UHF Transponder	OFF
2.	UHF Power Amplifier	OFF
3.	UHF Antenna Servo	OFF
4.	VHF Transceiver	OFF
5.	Intercom	OFF
6.	Television	OFF

Instrumentation

1.	PCM Telemetry	OFF
2.	Clock	OFF
3.	In-Flight Test System	OFF
4.	Recorder	OFF
5.	Sensors	OFF

Navigation and Guidance

1.	Inertial Meas. Unit	100 watts
2.	Optical Meas. Unit	OFF
3.	O.M.U. Coup. & Display	OFF
4.	Computer	20 watts (25% duty cycle)
5.	Power & Servo Assembly	20 watts
6.	I.M.U. Coup. & Display	12 watts
7.	Displays & Control	3 watts (25% duty cycle)
8.	Radar Altimeter	OFF
9.	Rendezvous/S.R. Radar	OFF
	TOTAL----------	155 watts

Stabilization and Control

1.	Strap Down Attitude Ref.	100 watts
2.	Guidance Coupler Unit	10 watts (25% duty cycle)
3.	Attitude & Translation C.U.	OFF
4.	Descent Abort Programmer	OFF
5.	Back-Up Ascent Programmer	OFF
6.	Gyro Rate Sensor (3 axis)	OFF
7.	Comparator In-Flight Test System	OFF
	TOTAL----------	110 watts

Displays

1.	R & R Indicator	OFF
2.	H & H Indicator	OFF
3.	S & C Indicator	OFF (would use N & G displays)
4.	Misc. Indicator Lights	5 watts
5.	Lighting Displays	25 watts
	TOTAL----------	30 watts

Environmental Control

1.	Suit Compressor	25 watts (25% duty cycle)
2.	Glycol Pump	6 watts (25% duty cycle)
3.	Cabin Fan	10 watts (25% duty cycle)
4.	Sox Heater (left on moon)	--
5.	Controls (Temp.)	3 watts (25% duty cycle)
6.	Cat. Burn & Display	OFF
7.	Back-Pack Recharge	50 watts

NOTE: The average power levels indicated are based on the assumption that during the emergency contingency time the crew will utilize their back-packs for periods of time, thus enabling the suit compressor to be shut down. The theory goes as follows: the back packs are capable of four hour operation, therefore it should be possible to shut down the compressor for three out of every four hours with the fourth hour used to recharge the back packs. This being so, the average compressor power for the time involved would be 25 watts (25% duty cycle). The average power for the back-pack recharge works out to be 50 watts. The glycol pump and cabin fans would be similarly operated. The above assumes that other required back-pack consumables will be available.

TOTAL----------	94 watts (average) 175 watts (peak for one hour)

Crew Systems

1.	Suit Biological Sensor	OFF
2.	Exterior Position & Signal Lights	OFF
3.	Interior Area Lights	OFF

Electrical Power

Controls	50 watts

Propulsion

Transducers turned OFF

Reaction Control

Average power of 17 watts

The results of approach two are therefore:

Average Power	456 watts
Peak Power	537 watts
Kilowatt - Hours	456 (16.5) = 7.5 KW HRS.

The conclusion drawn is that for this particular approach the 50% module should be sized for a power level of 537 watts. But, there is one more step to take before the loop is closed. If two of the three 50% modules must be sized to handle the normal load, one 50% module must be capable of handling one half the normal load. The preliminary load analysis indicates that one-half the normal load will be roughly 860 watts. The condition that now arises is one in which the emergency condition, which requires less electrical power, is not compatible with the normal requirement for this approach. In other words, if each 50% module were sized to handle 537 watts, two 50% modules (required for normal operation) could handle only 1074 watts instead of the required 1720 watts. Inasmuch as designing for emergency operation would compromise normal operation, the conclusion is drawn that for this approach, the system should be sized for normal operation.

In accordance with load profile "C", the energy requirement for Ascent and Rendezvous (Phases 9, 10 and 11) is 10.3 KW HRS. for this approach.

Conclusion:

Approaches 1 and 2 have application to an unstaged power source configuration. If the power subsystem is staged, the conclusions are still valid.

The decision to be made concerning Mission "C" is whether the subsystem shall be designed for the "vehicle" emergency loads or for the "Electrical Power" emergency loads during Ascent and Rendezvous (Phases 9, 10 and 11). The difference in the required KW HRS is 5.4 (15.7 KW HRS vs. 10.3 KW HRS). A decision for the former points toward an unstaged system. A decision for the later indicates a staged configuration. It is recommended that the vehicle emergency be the criteria inasmuch as unusual demands on the crew and the LEM operation would be required for operation under the EPS emergency. A mission along the lines of profiles A or B indicates a staged system.

The last point is whether separate emergency provisions (over and above the normal configuration required to achieve a given reliability for crew safety) with the attendznt weight penalty, shall be provided for the LEM. It appears that a proper design for the normal condition will cover the emergency conditions.

NOTE: As previously mentioned, the conclusions drawn in this memo are based on load profile "C" previously described. If the rendezvous contingency time and/or loads change significantly (i.e. - much shorter duration similar to Mission A or B) the decision to stage or unstage the power subsystem will be affected.

SUMMARY OF REQUIREMENTS

	Column 1	2	3	4	5	6	7	8
	Phases 1-8 KWHRS	Phases 2-8 KWHRS	Considering Vehicle Emergency 9-11 KWHRS	Considering Electrical Power 9-11 KWHRS	Mission Requirements KWHRS			
					Total Columns 1 and 3	Total Columns 1 and 4	Total Columns 2 and 3	Total Columns 2 and 4
MISSION C (18 Hours From Moon Launch to Dock)	41.6	29.5	15.7	10.3	57.3	51.9	45.2	39.8
MISSION B (12 Hours From Moon Launch To Dock)	45.6	33.5	11.0	7.6	56.6	53.2	44.5	41.1
MISSION A (6 Hours From Moon Launch to Dock)	49.5	37.4	6.3	4.8	55.8	54.3	43.7	42.2

Notes

1) Phases 1 thru 8 assumes LEM will supply its trans Lunar Power Requirements.
2) Phases 2 thru 8 assumes CSM will supply LEM trans Lunar Power Requirements.
3) All figures are based on the Preliminary Load Analysis the results of which are presented in Memorandum L390-M03-2, dated 30 January 1963 and referenced documents therein.

SECTION VII - RESERVE AND GROWTH

Definitions

1. Reserve is defined as the amount of expendables (i.e: hydrogen, oxygen and water) required to provide for deviations in expected performance.

2. Growth is defined as:

   (a) The incremental increase in power required for equipment added to the Load Analysis, or

   (b) The incremental increase in power required by existing equipment, or

   (c) The incremental increase in energy required due to (1) and (2) above.

Discussion

The Lunar Excursion Module is expected to complete its mission within 48 hours after separation from the CSM. Of this time, it is expected that 24 hours will be expended as time required for Separation, Descent, and Lunar Stay Time. The Lunar Stay time is presently considered to include the time required for pre-launch checkout prior to initiation of the Ascent Stage separation from the Descent Stage. Mission "C" as described in the Technical Study of the Electrical Power Subsystem is considered to be a close description of the expected final mission profile. There are still some areas of the Mission Profile under discussion between GAEC, MSC, NAA, and MIT, notably the precise description of the rendezvous and docking trajectory including rendezvous contingency and the exact period of time that should be allowed for Lunar Stay. There is some thought that the Descent and Lunar Stay period should not be as long as 24 hours. Nevertheless, the Power Subsystem has been designed to operate over a 48 hour period in accordance with Mission "C". The difference between the time required for Ascent, rendezvous, rendezvous contingency, and docking; and 24 hours remaining at the end of the Lunar Stay period can be assigned to provide for reserve and growth requirements. Based on Mission "C" the margin for reserve and growth amounts to (24-18) hours x 790 watts average power during Lunar Stay or 4.74 KW HR. This amounts to a 7.7% margin. For design purposes, it is proposed to allow a 10% margin for reserve and growth in energy requirements. Therefore, an increase in weight is indicated over the effective weights used in this report of approximately 81 to 113 lbs. assuming that we need provide only 2.3% of additional energy to meet our goal for reserve and growth. Ten percent is also the goal selected by NAA for the CSM.

The selected configuration has a growth capability of 100 watts maximum load without provision of additional equipment. In the event of a growth in power greater than 100 watts, we can provide for it with the addition of one more fuel cell assembly and a suitable revision to tank capacity if the energy growth exceeds the existing reserve.